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WMOST Climate Automation Programs (WCAP) Instructions v.1: SWAT Batch Climate Runs, Hydrologic Comparison Assessment Module (HCAM-R) for SWAT, HAWQS

Office of Research and Development
Center for Environmental Measurement and Modeling

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WMOST Climate Automation Programs (WCAP) Instructions: Version 1

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List of Acronyms

AMPL -- A Mathematical Programming Language

BMP -- Best Management Practices

CAM-WRAP -- Climate Automation Module Wrapper Program

CRP -- Crop

CTRL -- Control

DIFF -- Difference

EPA -- U.S. Environmental Protection Agency

FRS -- Forest

GCM -- General Circulation Model

HAWQS -- Hydrologic and Water Quality System

HAY -- Hay

HCAM -- Hydro-Climate Automation Module

HCAMR -- Hydro-Climate Automation Module R Version

HP -- HydroProcessor

HRU -- Hydrologic Response Unit

HSPF -- Hydrological Simulation Program in Fortran

HUC -- Hydrologic Unit Code

ID -- Identification

KGw – Groundwater recession coefficient

LASSO -- Locating and Selecting Scenarios Online tool

LULC -- Land Use Land Cover

NEOS -- Network-Enabled Optimization System

OM -- Operation & Management

ORD -- Office of Research and Development

PDF -- Portable Document Format

PREC -- Precipitation

QA -- Quality Assurance

RCHG -- Recharge

RNG -- Range

RNGE -- Range

SWAT -- Soil and Water Assessment Tool

SWMM -- Stormwater Management Model

SYLD – Sediment yield

TEMP -- Temperature

TMDL -- Total Maximum Daily Load

TN -- Total Nitrogen

TP -- Total Phosphorus

TSS -- Total Suspended Solids

URL -- Urban

USC – Upper Soldier Creek

WCAP -- WMOST Climate Automation Programs

WIP -- Watershed Implementation Plan

WMOST -- Watershed Management Optimization Tool

WTL -- Wetland

WTR -- Water

1 Introduction

The Watershed Management Optimization Tool (WMOST) is an Excel-based tool designed to aid decision making in integrated water resources management. It is meant to be run for small watersheds (HUC10 to HUC12 scale) and over a range of planning years. WMOST uses baseline runoff and recharge time series for both water and pollutant loadings from models such as the Soil and Water Assessment Tool (SWAT), Hydrological Simulation Program in Fortran (HSPF), and the Stormwater Management Model (SWMM), which are in turn modified to reflect various management practices. WMOST is linked behind the scenes with EPA's SWMM model to simulate the effects of stormwater best management practices (BMPs) on hydrology and loads. While simulation of a few agricultural conservation practices are also coded within WMOST itself, the user can simulate many more agricultural practices, e.g., no-till, contour plowing, terracing, grassed swales, etc., using a SWAT model and then incorporating the output time series into WMOST as "managed sets". WMOST sets up optimization problems in files described in the AMPL language which the user uploads to the online NEOS server where least cost optimizations take place.

The WMOST Climate Automation Programs (WCAP) are a suite of WMOST version 3.1 add-ons that automate the creation and processing of runoff and recharge time series that reflect varying climate change scenarios. The suite of WCAP programs include the SWAT batch climate runs code, Hydro-Climate Automation Module (HCAM)[1], Hydro-Climate Automation Module R Version (HCAM-R), and the Climate Automation Module wrapper program (CAM-WRAP). Together with the existing capabilities of WMOST, these tools can be used with ScenCompare[2], the WMOST Climate Scenario Viewer and Comparison Post Processor (EPA, 2018c) to compare optimization results across a range of climate change scenarios. These instructions document the use of three WCAP programs: SWAT batch climate runs code, HCAM-R, and CAM-WRAP, including software requirements, data requirements, and recommended folder structure[3]. A detailed, step-by-step case study is included in Appendix D to demonstrate the use of these programs.

HCAM and HCAM-R automate the functionality of the Baseline Hydrology and Stormwater Hydrology Modules within WMOST v3.1. HCAM automates the use of the Stormwater Hydrology Module within WMOST for different climate scenarios and documentation was previously published for that application (EPA, 2021). Similarly, HCAM-R is an R program (EPA, 2021) that allows the user to process multiple Soil & Water Assessment Tool (SWAT)[4] model runs that simulate agricultural Best Management Practices (BMP) not otherwise included within WMOST over varying climate scenarios.[5] The steps represented in Figure 2 summarize the process by which users can utilize HCAM-R. As shown, HCAM-R facilitates the use of multiple SWAT watershed model runs driven by multiple scenarios of future changes in temperature and precipitation and prepared as time series inputs to the model. There are numerous sources for future changes in temperature and precipitation, including downscaled General Circulation Models (GCMs). For example, EPA provides the online LASSO tool[6], which allows users to estimate change factors for temperature and precipitation between current and future climate scenarios across multiple GCMs. Users could apply these change factors to historical climate time series and then use the SWAT batch

[1] This program is discussed in more detail on EPA's website.
[2] ScenCompare can be used with HCAM-R and CAM-WRAP outputs, but only after model optimization and WMOST results processing.
[3] If following the tutorial, please use the folder structure included with the tutorial data files. We recommend using a similar folder structure (described in more detail in the following sections) for maximum compatibility with the various codes. If needed, users can use an alternative folder structure, but would need to make associated changes to the various codes.
[4] HCAM-R is compatible with SWAT models developed using the HAWQS platform (https://hawqs.tamu.edu/).
[5] This differs from HCAM which allows the user to batch run stormwater BMP simulations with the Storm Water Management Model (SWMM) to generate managed runoff/recharge time series over varying climate scenarios.
[6] https://lasso.epa.gov/

climate runs code (SWAT Batch Climate Runs section and Appendix A – SWAT Batch Climate Runs Code) to rerun base SWAT watershed models with updated weather files to generate climate scenario hydrology and loading time series for use with HCAM-R.

CAM-WRAP is an R-based wrapper program that allows users to combine the capabilities of HCAM and HCAM-R to model a holistic set of urban and agricultural BMPs to meet hydrology and water quality targets. Figure 3 summarizes the process by which users can utilize CAM-WRAP to combine HCAM and HCAM-R capabilities. Such functionality is needed to support various applications such as evaluating the outcome of a prescribed management strategy – e.g., a Watershed Implementation Plan (WIP) to meet Total Maximum Daily Load (TMDL) requirements – over multiple plausible future temperature and rainfall scenarios to determine under what conditions the strategy might be expected to fail to meet performance requirements.

Users who are unfamiliar with WMOST model inputs and outputs should refer to the WMOST documentation (EPA, 2018a; EPA, 2018b).

Figure 1: Process flow diagram of user steps to use HCAM, HCAM-R and CAM-WRAP

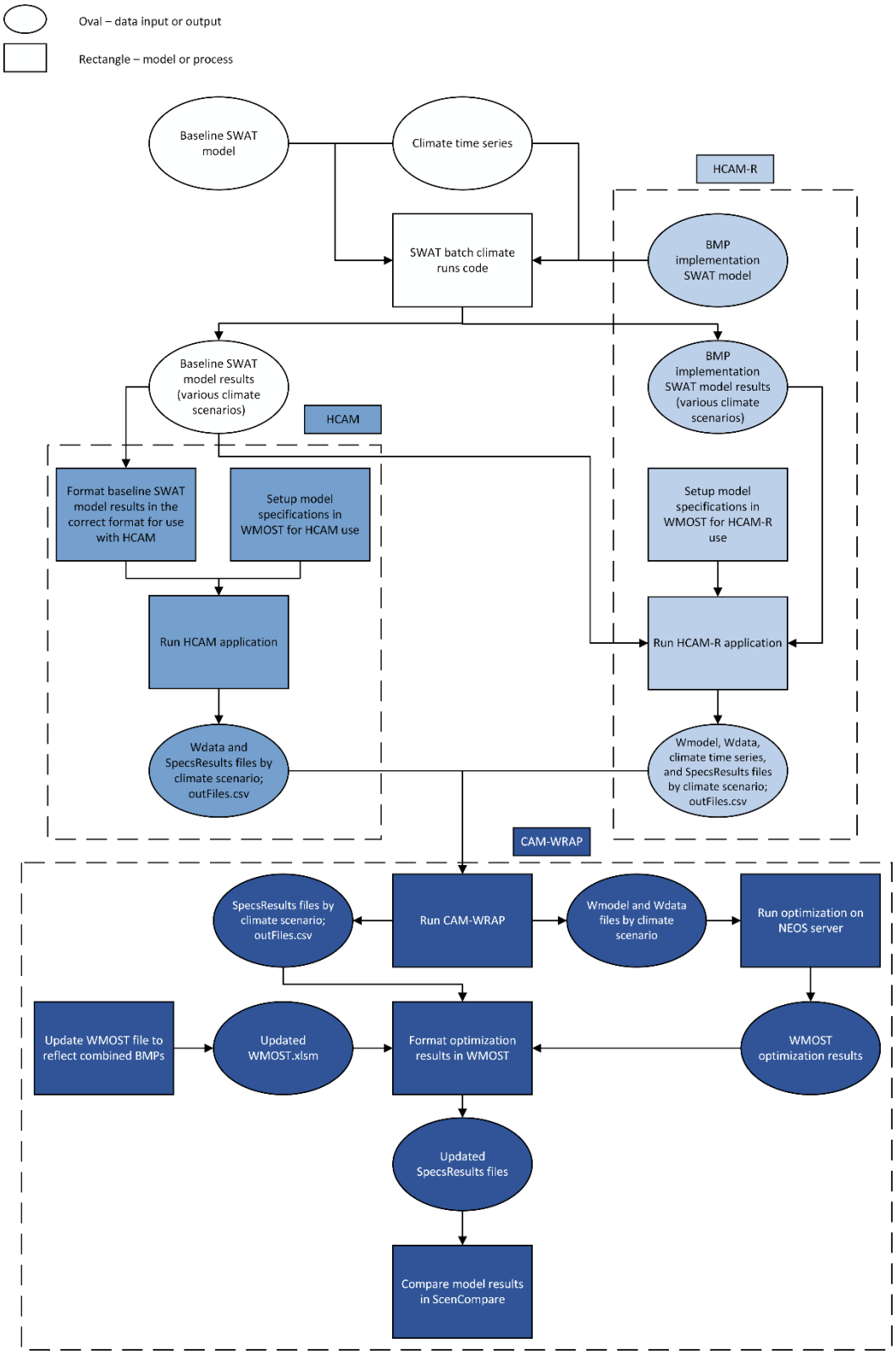


Figure 2: Process flow diagram of user steps to use HCAM-R

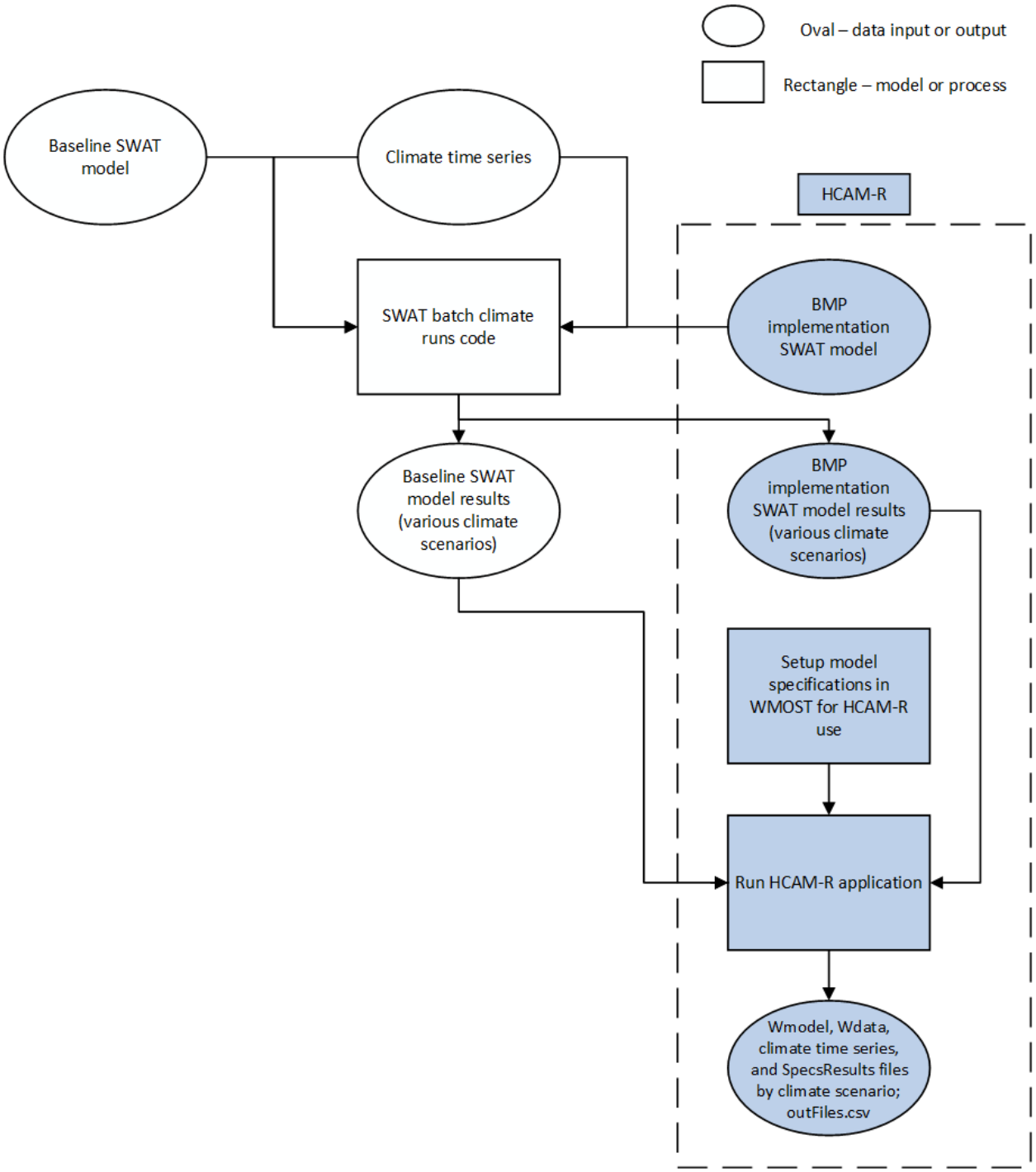
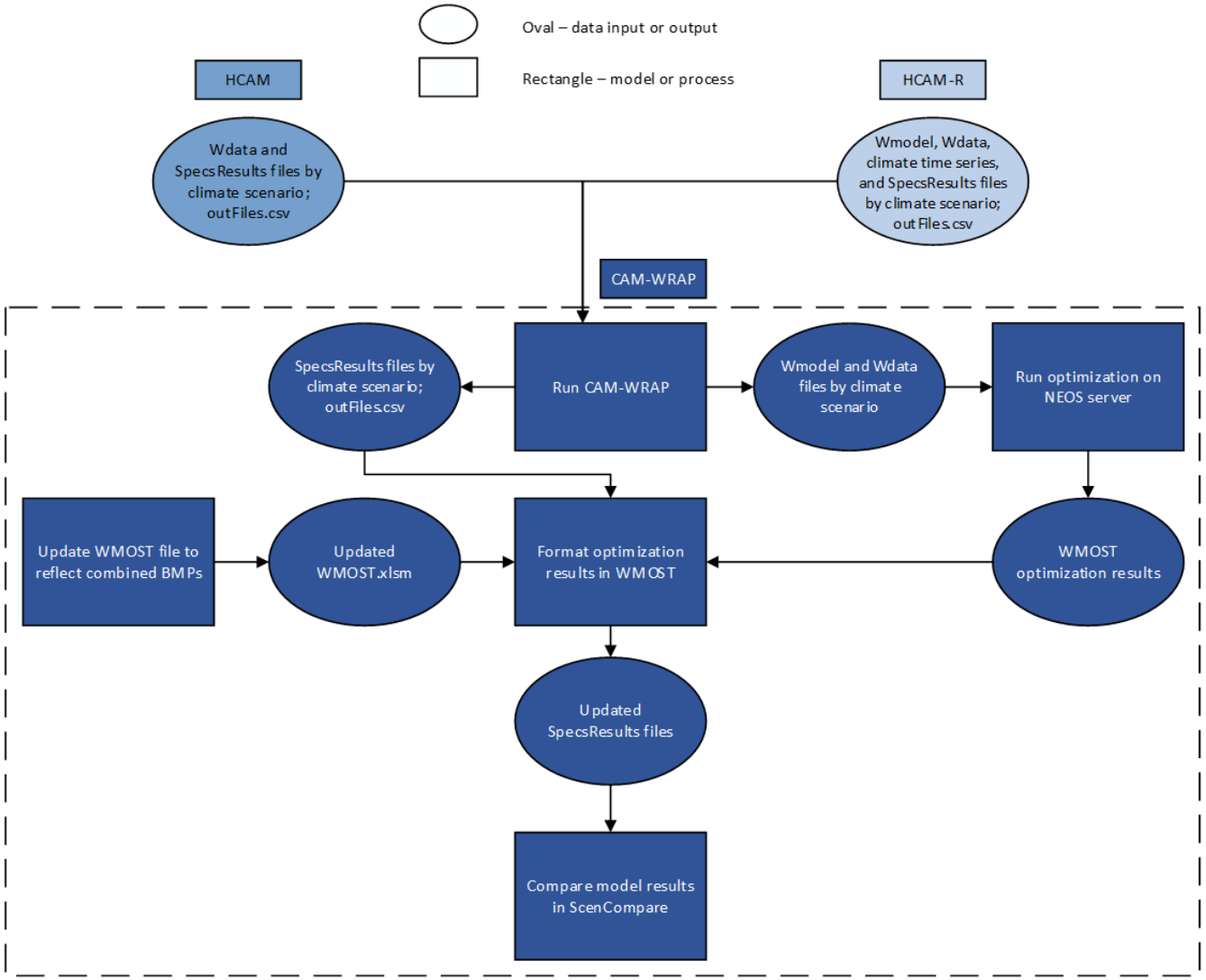


Figure 3: Process flow diagram of user steps to use CAM-WRAP



2 SWAT Batch Climate Run Code

The purpose of the SWAT batch climate runs code is to execute a series of SWAT model runs that iterate through SWAT modeling scenarios (*e.g.,* varying agricultural BMP modeling scenarios) and future climate time series for the same baseline SWAT watershed model. The outputs from the code can then be used as input to HCAM-R (see Figure 1).

2.1.1 R Packages

The SWAT batch climate runs code was built using R version 4.1.0. Users must install the following packages prior to running the SWAT Batch Climate Runs R code: dplyr (1.0.6), tidyr (1.1.3), stringr (1.4.0), and lubridate (1.7.10).

2.2 Folder Structure

The following folder structure is recommended for running this code. The first section is an overview of the recommended folder structure and of the content of the various folders. The second section provides more details on the files found within the folders, including example screenshots.

In the lists below, file folders are denoted by a folder icon ( ) and the recommended name of the folder is provided in parentheses. Any item (*e.g.,* folders, files, lists) that are also input variables to the SWAT batch climate runs code are denoted in *italics* and any output folders created by WMOST-related programming (*e.g.,* WMOST or HCAM) are denoted in **bold**.

2.2.1 Recommended Folder Structure

- Batch Climate Runs Project Folder
  - *Climate_Data_path* (Inputs): Climate Data Input Files
    - Precipitation Data Folder
      - Precipitation Files
    - Temperature Data Folder
      - Temperature Files
  - *SWAT_model_inpath* (SWAT_Models): SWAT Model Files [Note: This is the same basic structure as used in the HCAM-R.]
    - BMP Scenario 1 (e.g., Contouring)
      - TxtInOut
        - SWAT Model Files
    - BMP Scenario n
      - TxtInOut
        - SWAT Model Files
  - *SWAT_model_outpath*: Updated SWAT Files
    - **Results**: SWAT Model Output Files [Note: This is the same basic structure as used in the HCAM-R.]
      - BMP Scenario 1 (**folder name** defined by *Scenarios* variable)

        - Climate Scenario 1 (**folder name** defined by *Climate_Scenarios* variable)
            - SWAT Model Outputs (oput[].hru) and SWAT Model Run Log File
        - Climate Scenario n (**folder name** defined by *Climate_Scenarios* variable)
            - SWAT Model Outputs (oput[].hru) and SWAT Model Run Log File
    - BMP Scenario n (**folder name** defined by *Scenarios* variable)
        - Climate Scenario 1 (**folder name** defined by *Climate_Scenarios* variable)
            - SWAT Model Outputs (oput[].hru) and SWAT Model Run Log File
        - Climate Scenario n (**folder name** defined by *Climate_Scenarios* variable)
            - SWAT Model Outputs (oput[].hru) and SWAT Model Run Log File
- **Climate_Files**: Updated SWAT Model Input Files
    - BMP Scenario 1 (**folder name** defined by *Scenarios* variable)
        - Climate Scenario 1 (**folder name** defined by *Climate_Scenarios, Emission_Scenario,* and *Fut_Time_Frame* variables)
            - SWAT Model Inputs (pcp1.pcp and tmp1.tmp)
        - Climate Scenario n (**folder name** defined by *Climate_Scenarios, Emission_Scenario,* and *Fut_Time_Frame* variables)
            - SWAT Model Inputs (pcp1.pcp and tmp1.tmp)
    - BMP Scenario n (**folder name** defined by *Scenarios* variable)
        - Climate Scenario 1 (**folder name** defined by *Climate_Scenarios, Emission_Scenario,* and *Fut_Time_Frame* variables)
            - SWAT Model Inputs (pcp1.pcp and tmp1.tmp)
        - Climate Scenario n (**folder name** defined by *Climate_Scenarios, Emission_Scenario,* and *Fut_Time_Frame* variables)
            - SWAT Model Inputs (pcp1.pcp and tmp1.tmp)

2.2.2 Detailed Folder Structure

- Batch Climate Runs Project Folder
    - *Climate_Data_path* (Inputs): Climate Data Input Files
        - Precipitation Data Folder (precipitation_yyyytoyyyy) (Figure 4)
            - Precipitation Files
                - Naming convention: precmm_fut[*Subbasins*]_[*Climate_Scenarios*]1[*Emission_Scenario*][*Fut_Time_Frame*].csv

        - Temperature Data Folder (temperature)
            - Temperature Files
                - Naming convention: tempdegc_fut[*Climate_Scenarios*].csv
    - *SWAT_model_inpath* (SWAT_Models): SWAT Model Files [Note: This is the same basic structure as used in the HCAM-R.]
        - The model folders are currently set up as [Scenario name]/TxtInOut/[Model files]
        - BMP Scenario 1 (e.g., Contouring)
            - TxtInOut
                - SWAT Model Files
        - BMP Scenario n
            - TxtInOut
                - SWAT Model Files
    - *SWAT_model_outpath*: Updated SWAT Files
        - **Results**: SWAT Model Output Files [Note: This is the same basic structure as used in the HCAM-R.]
            - Model outputs will be printed to separate folders: **Results**/[***Scenarios***]/[***Climate_Scenarios***]/[oput files]
            - BMP Scenario 1 (**folder name** defined by *Scenarios* variable)
                - Climate Scenario 1 (**folder name** defined by *Climate_Scenarios* variable)
                    - SWAT Model Outputs (oput[].hru) and SWAT Model Run Log File
                - Climate Scenario n (**folder name** defined by *Climate_Scenarios* variable)
                    - SWAT Model Outputs (oput[].hru) and SWAT Model Run Log File
            - BMP Scenario n (**folder name** defined by *Scenarios* variable)
                - Climate Scenario 1 (**folder name** defined by *Climate_Scenarios* variable)
                    - SWAT Model Outputs (oput[].hru) and SWAT Model Run Log File
                - Climate Scenario n (**folder name** defined by *Climate_Scenarios* variable)
                    - SWAT Model Outputs (oput[].hru) and SWAT Model Run Log File
        - **Climate_Files**: Updated SWAT Model Input Files
            - Updated versions of pcp1.pcp and tmp1.tmp will be printed to separate folders: **Climate_Files**/[***Scenarios***]/[***Climate_Scenarios***][***Emission_Scenario***][***Fut_Time_Frame***]

- The code will save the original pcp1.pcp and tmp1.tmp files to **Climate_Files**/[***Scenarios***]/**Pre_Batch**. If you run into an error while running the code, replace the files within the SWAT model folder path with these files before rerunning the code.
- BMP Scenario 1 (**folder name** defined by *Scenarios* variable)
    - Climate Scenario 1 (**folder name** defined by *Climate_Scenarios,* *Emission_Scenario,* and *Fut_Time_Frame* variables)
        - SWAT Model Inputs (pcp1.pcp and tmp1.tmp)
    - Climate Scenario n (**folder name** defined by *Climate_Scenarios,* *Emission_Scenario,* and *Fut_Time_Frame* variables)
        - SWAT Model Inputs (pcp1.pcp and tmp1.tmp)
- BMP Scenario n (**folder name** defined by *Scenarios* variable)
    - Climate Scenario 1 (**folder name** defined by *Climate_Scenarios,* *Emission_Scenario,* and *Fut_Time_Frame* variables)
        - SWAT Model Inputs (pcp1.pcp and tmp1.tmp)
    - Climate Scenario n (**folder name** defined by *Climate_Scenarios,* *Emission_Scenario,* and *Fut_Time_Frame* variables)
        - SWAT Model Inputs (pcp1.pcp and tmp1.tmp)

The following figures show the exact folder structure utilized by the current version of the code.

Figure 4: Precipitation data files found within *Climate_Data_Path*/[Precipitation Data Folder] folder

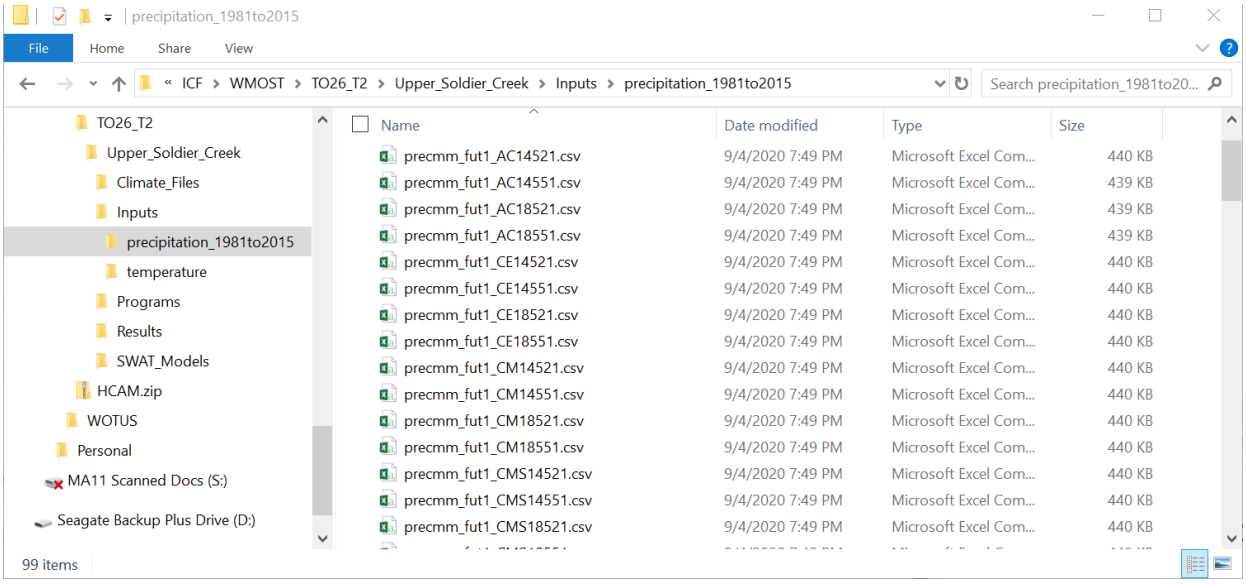


Figure 5: SWAT model files in the folder structure *SWAT_model_inpath*/[*Scenarios*]/TxtInOut/

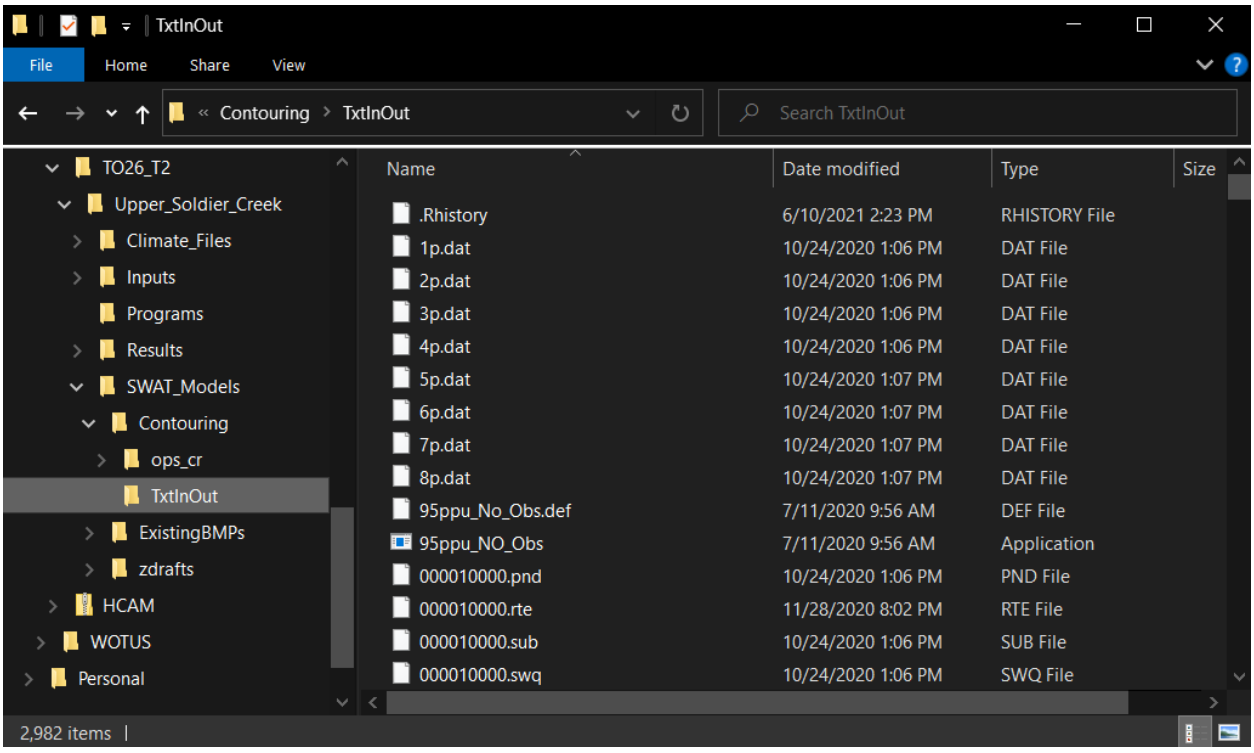
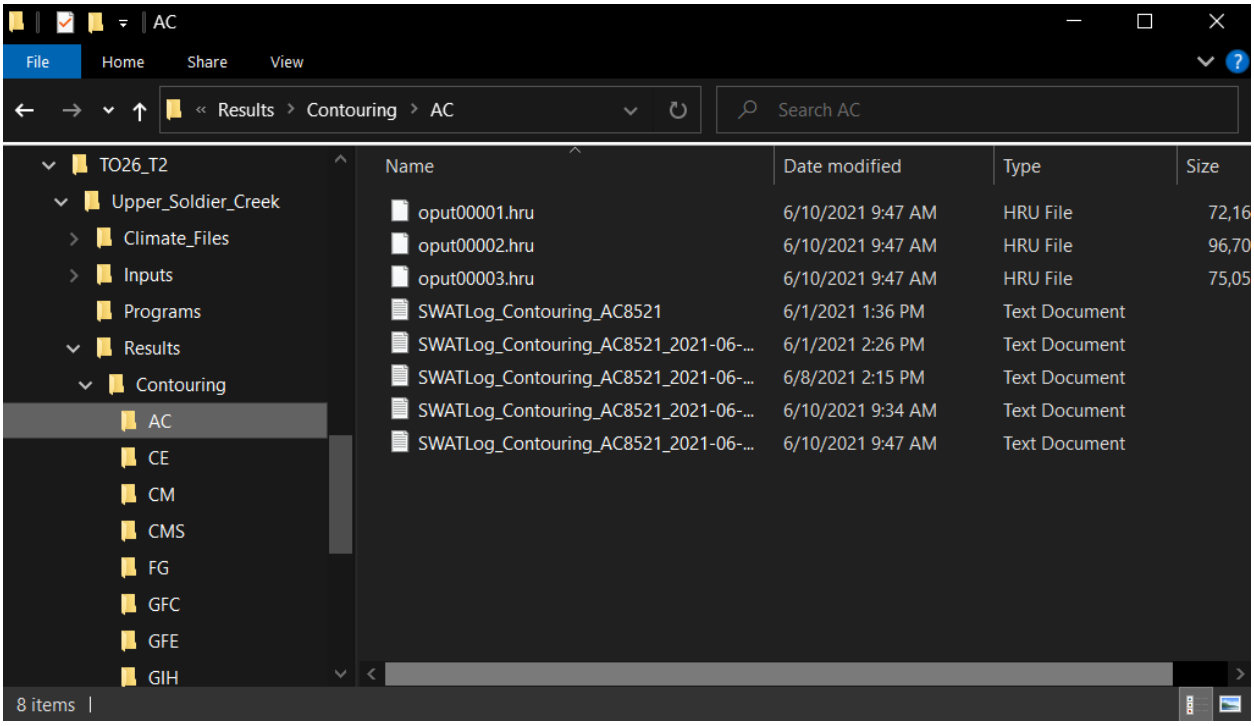


Figure 6: SWAT Model output files in the folder structure Results/[*Scenarios*]/[*Climate_Scenarios*]/



2.3 Variables to be Adjusted by User

Section 1 of the code covers variables that users may want to adjust before running the SWAT batch climate runs code. Below is a list of variable names and the associated data. The notes covered in this document are also available within the code itself, as are example input variables.

Table 1: Variable Descriptions (Section 1 of SWAT Batch Climate Runs Code)

Variable Name	Variable Description
Climate_Data_path	This file path should include all future climate data. See folder structure in Figure 4.
SWAT_model_inpath	This file path should include all of the SWAT models to be run. See folder structure in Figure 5.
SWAT_model_outpath	This file path is where a "Climate_Files" folder and "Results" folder will be written. See Figure 6.
Climate_Scenarios	This variable defines the abbreviations associated with the scenarios of interest.
Emission_Scenario	This variable defines the label denoting the emission scenario of interest.
Fut_Time_Frame	This variable defines the label denoting the future time frame of interest.
Subbasins	This variable defines the subbasins to be assigned updated precipitation and temperature information.
Variables	This variable is used to programmatically develop the relevant columns for this analysis. In particular, the tempdegc_fut[climate].csv files have mintemp and maxtemp columns that are needed for this analysis.
Scenarios	This variable specifies which SWAT modeling scenarios will be run.
Copy_Files	This variable represents the outputs of interest that will be copied into a "Results" folder. Since SWAT models can consist of several hundred or several thousand files, this code will only save relevant output files for each scenario instead of creating a separate folder for each scenario.
SWAT executable	This variable identifies the appropriate SWAT executable for the analysis.
WriteFiles/RunSWAT	These variables define which sections of the code are run.

3 HCAM-R

The HCAM-R R codes facilitate the use of SWAT as input to WMOST to evaluate the robustness of various agricultural management options in meeting hydrology or water quality targets under varying future climate conditions. Specifically, the HCAM-R codes extract data for WMOST optimization from a series of SWAT model runs that iterate through SWAT modeling scenarios (*i.e.,* varying agricultural BMP modeling scenarios that are not available in WMOST) and future climate time series for the same watershed.

The first code (01_HP_HCAM_DefineUserSpecs.R) processes outputs from a baseline SWAT model run to provide the user with watershed characteristic information. The code outputs two files: a template file, temp_UserSpecs.csv, that can be used to define user options for running the second code and a file, climate_timeseries.csv, summarizing the precipitation and temperature time series for the baseline SWAT model run so that the user can select their desired WMOST model optimization time frame. These files are discussed in more detail in the Inputs section below. The user should review these files to build an associated WMOST optimization model and generate interim Wmodel.mod, Wdata.dat, and SpecsResults.csv files for use with the second code. The user should also define their user options in the template file, temp_UserSpecs.csv, and resave it as UserSpecs.csv. The second code (02_HP_HCAM.R) gets run in two steps. The user first runs Part 1 through 4A of 02_HP_HCAM.R. to output scenario-specific Wdata.dat files and an HRU-level template file, temp_HRUSpecs.csv. The user should define the HRU-level options in the template file, temp_HRUSpecs.csv, and resave it as HRUSpecs.csv. The HRUSpecs.csv file is discussed in more detail in the Inputs section below. The user then runs Parts 4B through 6 of the 02_HP_HCAM.R code to output scenario-specific Wmodel.mod, SpecsResults.csv, outFiles.csv, and Climate.csv files. The scenario specific Wdata.dat and Wmodel.mod files are ready for input into the NEOS server. The SpecsResults.csv, outFiles.csv, and Climate.csv files can be used to process NEOS server results for eventual use as inputs to ScenCompare. Additional details on the recommended folder structure and model inputs and outputs are described in the following sections.

3.1 R Packages

The HCAM-R codes were built using R version 4.1.0. Users must install the following packages prior to running the HP HCAM R codes: reader (1.0.6), dplyr (1.0.6), tidyr (1.1.3), stringr (1.4.0), data.table (1.14.0), lubridate (1.7.10), and gsubfn (0.7).

3.2 Folder Structure

The following folder structure is recommended for running HCAM-R. The first section is an overview of the recommended folder structure and of the content of the various folders. The second section provides more details on the files found within the folders through example screen shots.

In the lists below, file folders are denoted by a folder icon () and the recommended name of the folder is provided in parentheses. Folder names in “quotes” refer to folder names required by HCAM. Please see the HCAM documentation for more details. Any item (*e.g.,* folders, files, lists) that are also input variables to HCAM-R are denoted in *italics* and any output folders created by WMOST-related programming (*e.g.,* WMOST or HCAM) are denoted in **bold**.

3.2.1 Recommended Folder Structure

-  *inpath* (Inputs)*:* HCAM-R Input Files
  - WMOST interim optimization and output files
  - HCAM-R template files

    - HCAM-R user specification files
- *outpath* (Outputs)*:* HCAM-R Output Files
    - Outputs from 01 and 02 HCAM-R codes
- *SWAT_model_inpath* (SWAT_Models): SWAT Model Files
    - BMP Scenario 1 (*e.g.,* Contouring)
        - TxtInOut
            - SWAT model files, including urban.dat, .gw, .sol, and .cio files
    - BMP Scenario n
        - TxtInOut
            - SWAT model files, including urban.dat, .gw, .sol, and .cio files
- **Results**: SWAT Model Output Files
    - **BMP Scenario 1**
        - **Climate Scenario 1**
            - oput[].hru
        - **Climate Scenario n**
            - oput[].hru
    - **BMP Scenario n**
        - **Climate Scenario 1**
            - oput[].hru
        - **Climate Scenario n**
            - oput[].hru

3.2.2 Detailed Folder Structure

- *inpath* (Inputs)*:* HCAM-R Input Files (Figure 7)
    - WMOST interim optimization and output files, including:
        - Wdata.dat (read into 02_HP_HCAM code)
        - Wmodel.mod (read into 02_HP_HCAM code)
        - Wcommand.amp (not altered by HCAM-R)
        - Wopt.opt (not altered by HCAM-R)
        - SpecsResults.csv (read into 02_HP_HCAM code)
    - Template files, including:
        - temp_UserSpecs.csv (developed in 01_HP_HCAM code)
        - temp_HRUSpecs.csv (developed in 02_HP_HCAM code)
    - User specification files, including:
        - UserSpecs.csv (updated by user based on temp_UserSpecs.csv)
        - HRUSpecs.csv (updated by user based on temp_HRUSpecs.csv)
- *outpath* (Outputs)*:* HCAM-R Output Files (Figure 8)
    - From 01_HP_HCAM code: climate_timeseries.csv

- From 02_HP_HCAM code: Wmodel.mod, Wdata.dat, and SpecsResults.csv files generated for each scenario and constituent (TN, TP, and TSS). The code also outputs Climate.csv and outFiles.csv files for use with WMOST results processing.

- *SWAT_model_inpath* (SWAT_Models)*:* SWAT Model Files (Figure 9) [Note: This is the same basic structure as used for the SWAT batch climate runs code]
  - The model folders are currently set up as [Scenario Name]/TxtInOut/[Model Files]
  - If running HCAM-R for a baseline climate scenario, the user must save relevant outputs into the same folder structure as the other climate scenarios (see below: SWAT Model Output Files)

- **Results***:* SWAT Model Output Files (Figure 10) [Note: This is the location where model outputs from the SWAT batch climate runs code are saved]
  - oput[].hru files from each scenario run, located in folders set up as [Scenario Name]/[Climate Scenario ID (*e.g.,* AC)]

Figure 7: HCAM-R input file folder, should reflect the file path specified in the *inpath* variable

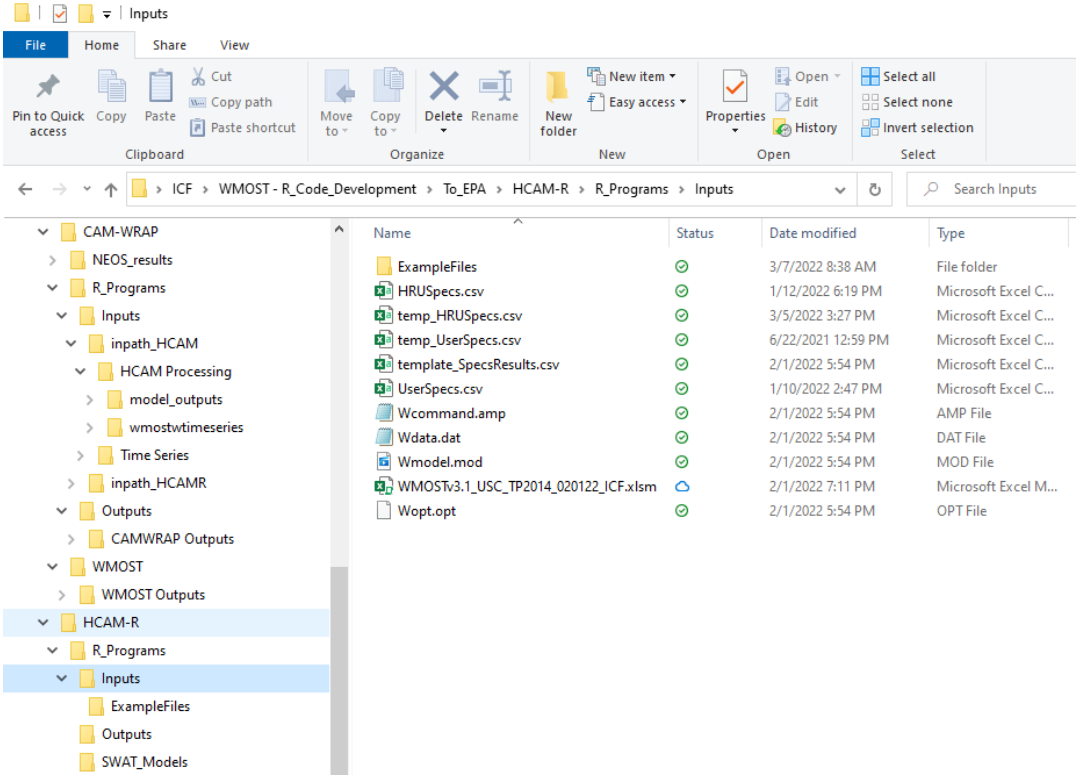


Figure 8: HCAM-R output file folder, should reflect the file path specified in the *outpath* variable

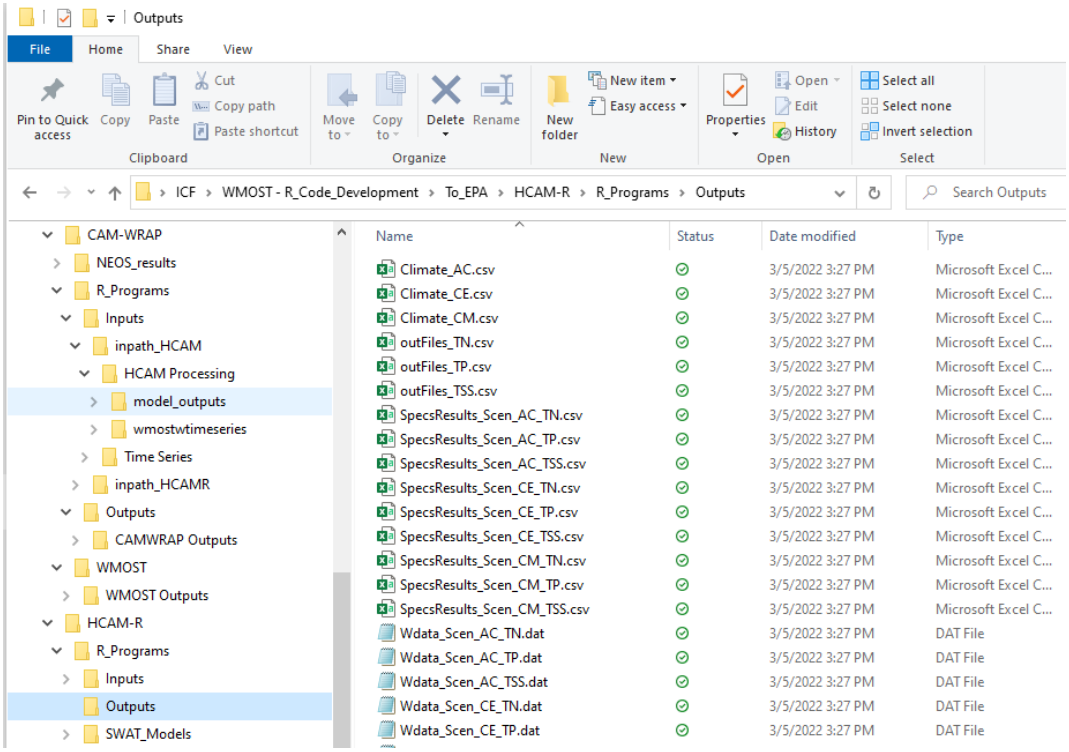


Figure 9: SWAT model files in the folder structure *SWAT_model_inpath*/[Scenario Name]/Txtinout/

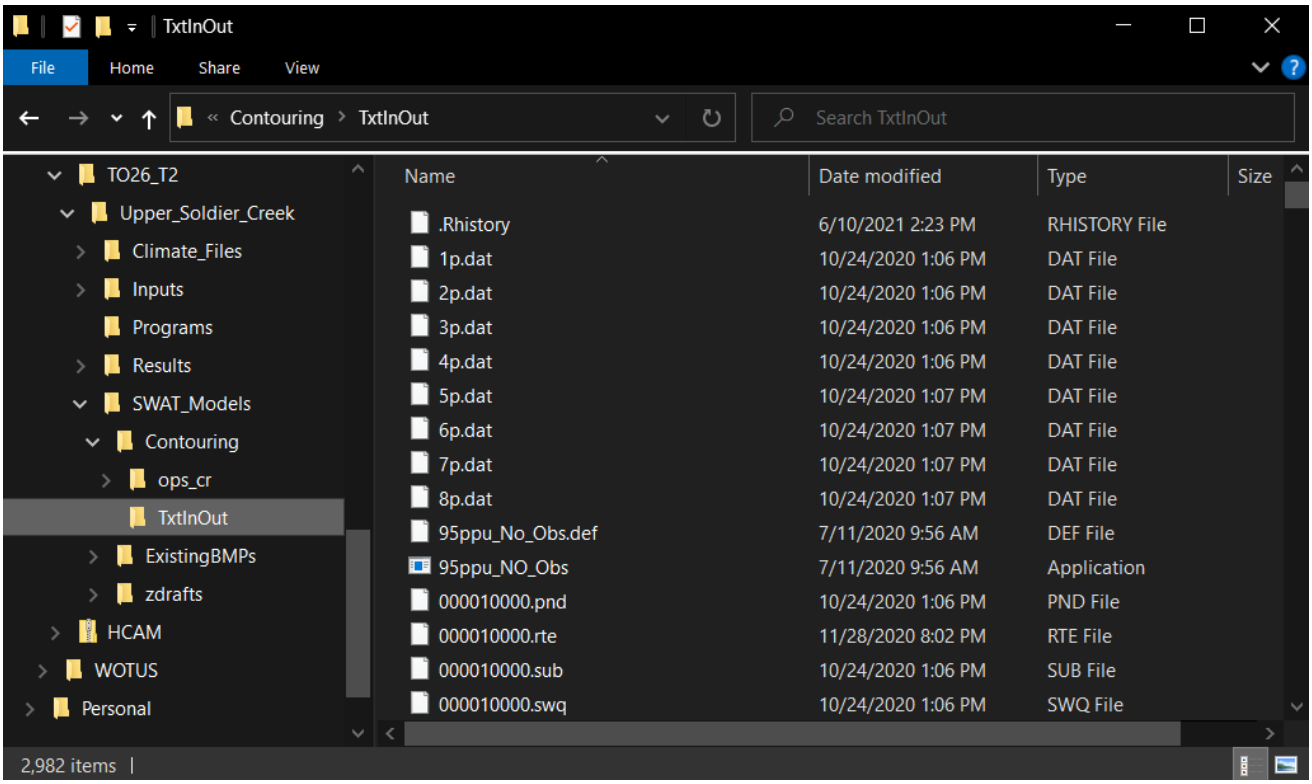
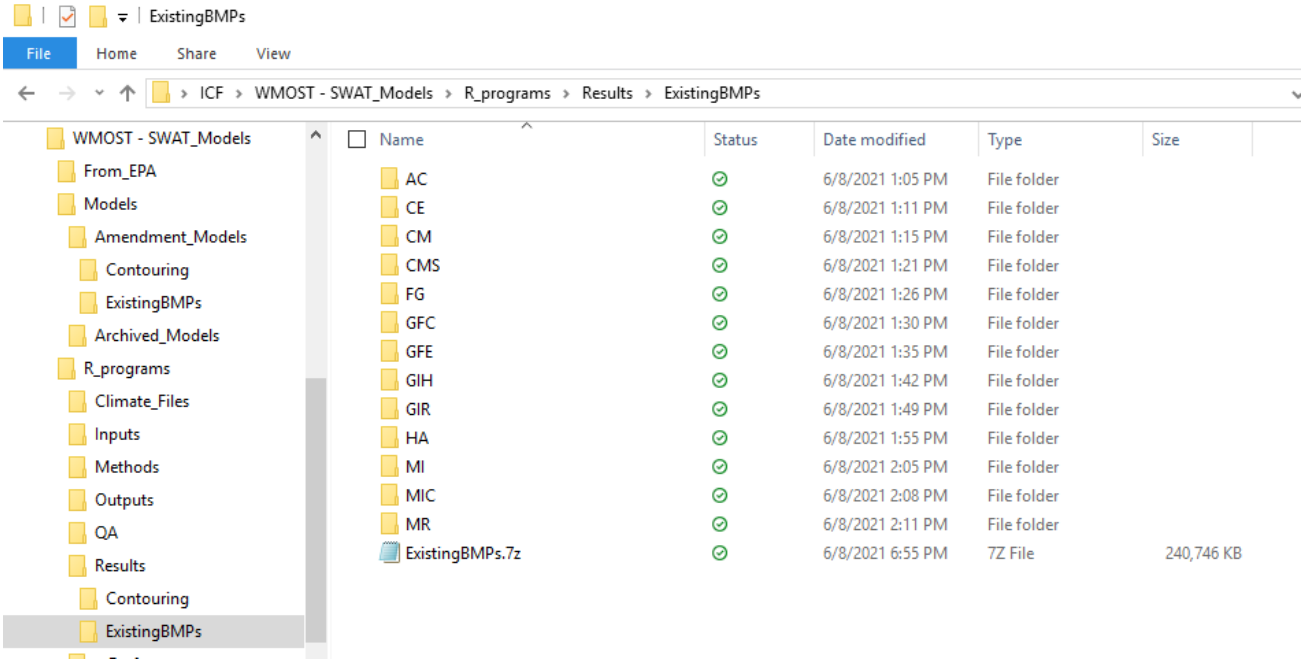


Figure 10: Climate scenario results folder created by the SWAT batch climate runs code in the folder structure Results/[Scenario Name]/[Climate Scenario ID]



3.3 Inputs

The following section provides more details on the required inputs for the HCAM-R codes, including external data files, user input files (UserSpecs.csv and HRUSpecs.csv), and variables specified within the codes themselves.

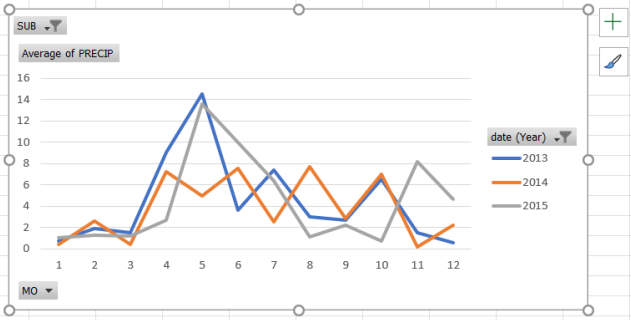
3.3.1 External Data Files

The user will need three sets of external data files to run the HCAM-R codes: interim WMOST optimization and output files to be updated by the HCAM-R codes, SWAT baseline and scenario (differing by both implemented management practices and climate scenarios) model outputs, and SWAT baseline and scenario (differing by implemented management practices) model files.

The user can generate the interim WMOST optimization and output files using data summarized by the 01_HP_HCAM.R code (temp_UserSpecs.csv and climate_timeseries.csv) and based on the desired modeling area. The temp_UserSpecs.csv file is discussed in more detail in the following section. The climate_timeseries.csv file summarizes the precipitation and temperature time series included in the baseline SWAT model so that the user can review trends among climate variables to help decide which time period to evaluate. Figure 11 provides a visual example of how the climate_timeseries.csv file can be used to evaluate the precipitation and temperature time series for the desired modeling area to determine a relevant WMOST modeling time frame.

Figure 11: Analysis of precipitation time series to select a WMOST modeling time frame

date	SUB	MO	DA	YR	PRECIP	TMP_AV
1/1/1997	1	1	1	1997	0	1
1/2/1997	1	1	2	1997	0	10.7
1/3/1997	1	1	3	1997	0	8.5
1/4/1997	1	1	4	1997	0	9.4
1/5/1997	1	1	5	1997	0	1.75
1/6/1997	1	1	6	1997	0	-4.95
1/7/1997	1	1	7	1997	0	-5.15
1/8/1997	1	1	8	1997	0	-3.65
1/9/1997	1	1	9	1997	0	-1.9
1/10/1997	1	1	10	1997	0	-9.9
1/11/1997	1	1	11	1997	0	-17.65
1/12/1997	1	1	12	1997	0	-15.95
1/13/1997	1	1	13	1997	0	-15.5
1/14/1997	1	1	14	1997	0	-12.4
1/15/1997	1	1	15	1997	1	-7
1/16/1997	1	1	16	1997	0	-8.85
1/17/1997	1	1	17	1997	0	-14.25
1/18/1997	1	1	18	1997	0	-12.3
1/19/1997	1	1	19	1997	0	-2.8
1/20/1997	1	1	20	1997	0	6.2
1/21/1997	1	1	21	1997	0	10.6
1/22/1997	1	1	22	1997	0	7.1
1/23/1997	1	1	23	1997	0	-2.35
1/24/1997	1	1	24	1997	0.3	-3.3
1/25/1997	1	1	25	1997	0	-9
1/26/1997	1	1	26	1997	2.8	-13.3
1/27/1997	1	1	27	1997	0	-12.35



HCAM-R users who are unfamiliar with WMOST model inputs and outputs should refer to the WMOST documentation (EPA, 2018a; EPA, 2018b) and HCAM user instructions (EPA, 2021) to fill out the WMOST interface and generate the necessary interim files, including Wdata.dat, Wmodel.mod, and SpecsResults.csv. As a note, HCAM-R calculates scenario-specific KGw values from SWAT output files (near the end of Part 2 in 02_HP_HCAM.R). In order to accurately include the updated KGw value in the Wmodel.mod (beginning of Part 4 in 02_HP_HCAM.R) and SpecsResults.csv files (Part 5 in 02_HP_HCAM.R) for each climate scenario, the user must set the KGw value in the WMOST model (Groundwater tab) to one. Setting the initial KGw value to one ensures that an accurate initial groundwater volume is included in the interimWmodel.mod file.

The SWAT model outputs and model files should be in the same folder structure as used to run the SWAT batch climate runs code (see SWAT Batch Climate Runs section). The user should have unique SWAT model files that reflect baseline and scenario (agricultural BMP implementation) runs. The unique SWAT model folders should include, at a minimum, urban.dat, .gw, .sol, and file.cio files. The SWAT model outputs, as generated by the SWAT batch climate runs code, should differ by both agricultural BMP scenario and climate scenario.

3.3.2 UserSpecs.csv

The 01_HP_HCAM.R code outputs a template User_Specs.csv file (temp_UserSpecs.csv) that the user should use to choose HCAM-R specifications. The HCAM-R download includes an ExampleFiles subfolder, with Example_UserSpecs.csv included there for reference. As shown in the example file (Figure 12), the user can use this file to choose which subbasins and HRUs to include in the model (*User_Choose* columns), the model start and end date, and file paths to the SWAT model outputs of interest (*Scenario_Name* column).

The user must specify file folders for the *Scenario_Name* column, numeric values for the *Managed_Sets* column, and climate scenario abbreviations for the *Climate_Scenario* column in the UserSpecs.csv file. File paths input into the *Scenario_Name* column are based on SWAT model outputs from the **Results** subfolder after running the SWAT batch climate runs code. Climate scenario abbreviations should match the final subfolder listed in the *Scenario_Name* column.

In addition, the order in which the user defines *Managed_Sets* in the UserSpecs.csv file must match the order in which the user defines managed sets in the *ManagedSets* character vector of the 02_HP_HCAM code. For example, within the example file, Managed_Set 1 refers to the ExistingBMPs managed set, while Managed_Set 2 refers to the Contouring managed set. In the 02_HP_HCAM.R code, the *ManagedSets* character vector is defined

as ManagedSets <- c(ExistingBMPs, Contouring), where element 1 of the vector is ExistingBMPs and element 2 is Contouring.

3.3.3 HRUSpecs.csv

The 02_HP_HCAM.R code outputs a template HRU_Specs.csv file (temp_HRUSpecs.csv) that the user should use to choose WMOST model specifications. The HCAM-R download includes an ExampleFiles subfolder, with Example_HRUSpecs.csv included there for reference. As shown in the example file (Figure 13), the user can use this file to choose WMOST model specifications, including HRU minimum and maximum area, capital and O&M costs for BMP application to the various HRUs, mimicking selections on the Land_Use tab in WMOST. The user can also use this file to choose WMOST model specifications for the model interest rate and planning horizon, mimicking selections on the Infrastructure tab in WMOST.

The order of aggregate HRUs in the HRUSpecs.csv file should match the order of aggregate HRUs defined in the UserSpecs.csv file. This order can be adjusted within the 02_HP_HCAM.R code of the HCAM-R code.

Figure 12: Example_UserSpecs.csv

SUB_CHOOSE	User_Choose_SUB	SUB	HRU	LULC	SOIL	SLOPE	User_Choose_HRU	User_Agg_HRU_ID	Possible_Date_Range	User_StartDate_ YYYY.MM.DD	User_EndDate_ YYYY.MM.DD	Scenario_Name	Managed_Sets	Climate_Scenario
1	X	1	1	FRST	KS311	0-1	X	FRS	Between 1995-01-01 and 2015-12-31	1/1/2014	12/31/2014	C:\Users\50367\ICF\WMOST - R_Code_Development\HCAM_R\	1	AC
2	X	1	2	HAY	KS194	0-1	X	HAY				C:\Users\50367\ICF\WMOST - R_Code_Development\HCAM_R\	2	AC
3	X	1	3	RNGB	KS194	0-1	X	RNG				C:\Users\50367\ICF\WMOST - R_Code_Development\HCAM_R\	1	CE
4		1	4	CWHT	KS311	0-1	X	CRP				C:\Users\50367\ICF\WMOST - R_Code_Development\HCAM_R\	2	CE
5		1	5	HAY	KS132	0-1	X	HAY				C:\Users\50367\ICF\WMOST - R_Code_Development\HCAM_R\	1	CM
6		1	6	SYWW	KS344	0-1	X	CRP				C:\Users\50367\ICF\WMOST - R_Code_Development\HCAM_R\	2	CM
7		1	7	URHD	KS311	0-1	X	URL						
8		1	8	CORN	KS311	0-1	X	CRP						
		1	9	FRSD	KS344	0-1	X	FRS						
		1	10	SOYB	KS344	0-1	X	CRP						
		1	11	RNGE	KS311	0-1	X	RNG						
		1	12	WETF	KS344	0-1	X	WTL						
		1	13	FRSD	KS311	0-1	X	FRS						
		1	14	RNGB	KS344	0-1	X	RNG						
		1	15	SOYB	KS194	0-1	X	CRP						
		1	16	SOYC	KS194	0-1	X	CRP						
		1	17	CSOY	KS194	0-1	X	CRP						
		1	18	URLD	KS344	0-1	X	URL						
		1	19	FRSD	KS194	0-1	X	FRS						

Figure 13: Example HRUSpecs.csv

WMOST_HRU_ID	WMOST_HRU_Name	Baseline_Area_acre	Minimum_Area_M	Maximum_Area_I	Initial_Cost_to_	OM_Cost_Mar	Minimum_Area_Ma	Maximum_Area_M	Initial_Cost_to_C	OM_Cost_Manage	Interest_Rate_perc	Planning_Horizon_yrs
1	Forested	7310.730661	7310.730661	7310.730661	-9	-9	0	0	-9	-9	3	20
2	Soybean	1846.090715	1846.090715	1846.090715	-9	-9	0	1846.090715	1292.263501	553.8272145		
3	Range	23482.39482	23482.39482	23482.39482	-9	-9	0	23482.39482	11741.19741	70.44718447		
4	Soy-Corn Rotation	6565.86155	6565.86155	6565.86155	-9	-9	0	6565.86155	656.586155	32.82930775		
5	Corn-Soy Rotation	7382.993627	7382.993627	7382.993627	-9	-9	0	7382.993627	6644.694264	36.91496814		
6	Urban	2791.430528	2791.430528	2791.430528	-9	-9	0	0	-9	-9		

3.3.4 Variables to be Adjusted in the HCAM-R Codes by User

The HCAM-R codes include variables that users may want to adjust before running HCAM-R. No changes to file names or structure are required to run through the CAM-WRAP tutorial. Changes may need to be made when supplying new data or in other instances like if users do not want to consider direct deposition to streams from cattle grazers. Below is a list of variable names and the associated code/files and variable description. The notes covered in this document are also available within the codes themselves.

There are several locations in the codes marked "## NOTE TO USER:". Please read through these statements and adjust variables as needed before progressing through the code.

Table 2: HCAM-R Variable Descriptions

Associated Code/File	Variable Name	Variable Description
Both 01_HP_HCAM_DefineUserSpecs.R and 02_HP_HCAM.R	*inpath*	This file path should point to the folder that includes all input files for running HCAM-R. See Figure 7.
Both 01_HP_HCAM_DefineUserSpecs.R and 02_HP_HCAM.R	*SWAT_model_inpath*	This file path should point to the folder that includes SWAT model files for each modeling scenario. See Figure 9.
Both 01_HP_HCAM_DefineUserSpecs.R and 02_HP_HCAM.R	*outpath*	This file path is where outputs of the 01_HP_HCAM and 02_HP_HCAM codes will be written. See Figure 8.
01_HP_HCAM_DefineUserSpecs.R	*Scenarios*	This variable defines the baseline SWAT model in the 01_HP_HCAM code.
02_HP_HCAM.R	*const, ru_const_, re_const, ru_sum, and re_const*	These variables define constituents processed in the WMOST files. The current 02_HP_HCAM code includes nitrogen, phosphorus, and sediment, but the user can opt to include fewer constituents.
02_HP_HCAM.R	*dir_dep*	This selection allows the user to consider direct deposition to streams from cattle grazers in RNGE HRU runoff loadings if "YES" is specified.
02_HP_HCAM.R	*ManagedSets*	This variable defines the managed sets considered in the 02_HP_HCAM code.
02_HP_HCAM.R	*agg_HRU_vec*	This specification allows the user to customize the order of aggregate HRU identifiers.
Specification within UserSpecs.csv	*Scenario_Name*	These user-specified file paths should point to the folders that include outputs from the SWAT model climate scenario runs. See Figure 9.
Specification within UserSpecs.csv	*Managed_Sets*	This column indicates the managed set number that corresponds to the user-specified file path in the *Scenario_Name* column.
Specification within UserSpecs.csv	*Climate_Scenario*	This column indicates the climate scenario identifier that corresponds to the user-specified file path in the *Scenario_Name* column.

Associated Code/File	Variable Name	Variable Description
Specification within HRUSpecs.csv	*Baseline_Area_acre, Minimum_Area_Managed _Set_[Managed Set Number]_acre, Maximum_Area_Managed _Set_[Managed Set Number]_acre, Initial_Cost_to_Conserve_ Managed_Set_[Managed Set Number]_peracre, OM_Cost_Managed_Set_[Managed Set Number]_peracre, Interest_Rate_perc, Planning_Horizon_yrs*	These user specified HRU acreage, cost, interest, and planning horizon details inform values used in the wmodel_Scen_[Climate Scenario].mod files.

3.4 Outputs

The following section provides more details on outputs from the 01_HP_HCAM.R and 02_HP_HCAM.R codes, including an overall description of each output as well as its intended use.

The user runs Parts 1 through Part 4a of the 02_HP_HCAM.R code to output scenario-specific Wdata.dat files and an HRU-level user input file, temp_HRUSpecs.csv. The user should define the HRU-level options in temp_HRUSpecs.csv and resave it as HRUSpecs.csv. The user can then run through Parts 4B through 6 of the 02_HP_HCAM.R code to output scenario specific Wmodel.mod, SpecsResults.csv, outFiles.csv, and Climate.csv files. The scenario specific Wdata.dat and Wmodel.mod files are ready for input into the NEOS server. The SpecsResults.csv, outFiles.csv, and Climate.csv files can be used to process NEOS server results for eventual use as inputs to ScenCompare.

3.4.1 Outputs from 01_HP_HCAM.R

The 01_HP_HCAM.R code outputs two files: temp_UserSpecs.csv and climate_timeseries.csv. Both of these files should be used as input or to inform external inputs to the 02_HP_HCAM.R code. As they are eventually used as input files, they are described in more detail in Section 3.

3.4.2 Outputs from 02_HP_HCAM.R

The 02_HP_HCAM.R code outputs Wmodel.mod, Wdata.dat, SpecsResults.csv, Climate.csv, and outFiles.csv files. The 02_HP_HCAM.R code also outputs the temp_HRUSpecs.csv file, which is discussed in more detail in the Inputs section.

The Wdata.dat and SpecsResults.csv files are generated for each climate scenario and constituent (TN, TP, and TSS). The Wmodel.mod and Climate.csv files are generated for each climate scenario. The outFiles.csv files are generated for each constituent. For more detailed descriptions of these files, refer to the WMOST user guide (EPA, 2018b) and HCAM user instructions (EPA, 2021).

Users should combine the scenario specific Wmodel.mod and Wdata.dat files with other WMOST optimization files[7] (Wopt.opt and Wcommand.amp) to run the scenario model optimization on the NEOS server. Note that

[7] These optimization files are generated at the same time as the interimWmodel.mod and Wdata.dat files. See the WMOST or HCAM documentation for more details.

HCAM-R does not perform the model optimization. Users should refer to the WMOST user guide (EPA, 2018b) for detailed instructions on how to submit model files to the NEOS server for optimization.

Following model optimization, users should use the model results and outFiles.csv files to process the results using the WMOST interface. Users should refer to the HCAM user instructions (EPA, 2021) for detailed instructions on how to process model results. Users should then manually update the climate statistics in the updated SpecsResults.csv file using the data reflected in the Climate.csv file. The final updated SpecsResults.csv file can then be used as input to EPA's ScenCompare (EPA, 2018c) to facilitate the comparison of model optimization across climate scenarios.

4 CAM-WRAP

The CAM-WRAP R code allows users to combine the capabilities of HCAM and HCAM-R to evaluate the robustness of a holistic set of urban and agricultural BMPs, respectively, to meet hydrology and water quality targets under varying future climate conditions.

The CAM-WRAP code processes output files from the HCAM-R R codes and HCAM Excel application to provide the user with WMOST optimization files that include urban and agricultural BMPs processed by the separate programs. In particular, the user should adjust the file paths to point to the relevant program folders and run the CAM-WRAP.R code to output scenario-specific Wmodel.mod, Wdata.dat, SpecsResults.csv, and outFiles.csv. The scenario specific Wdata.dat and Wmodel.mod files are ready for input into the NEOS server. The SpecsResults.csv and outFiles.csv files can be used to process NEOS server results for eventual use as inputs to ScenCompare. Additional details on the recommended folder structure and model inputs and outputs are described in the following sections.

4.1 R Packages

The CAM-WRAP code was built using R version 4.1.0. Users must install the following packages prior to running the CAM-WRAP code: reader (1.0.6), dplyr (1.0.6), tidyr (1.1.3), stringr (1.4.0), and data.table (1.14.0).

4.2 Folder Structure

The following folder structure is recommended for running CAM-WRAP. The first section is an overview of the recommended folder structure and of the content of the various folders. The second section provides more details on the files found within the folders through example screen shots.

In the lists below, file folders are denoted by a folder icon ( ) and the recommended name of the folder is provided in parentheses. Folder names in "quotes" refer to folder names required by HCAM. Please see the HCAM documentation for more details. Any item (*e.g.,* folders, files, lists) that are also input variables to CAM-WRAP are denoted in *italics* and any output folders created by WMOST-related programming (*e.g.,* WMOST or HCAM) are denoted in **bold**.

4.2.1 Recommended Folder Structure

- *inpath_HCAM* (HCAM Project Folder)*:* HCAM Files; CAM-WRAP Input Files
  - "Time Series"
    - Climate time series input files
  - "HCAM Processing"
    - WMOST interim optimization and output files
    - **model_outputs**
      - Output files from HCAM
- *inpath_HCAMR* (HCAM-R Project Folder/Outputs): HCAM-R Output Files; CAM-WRAP Input Files
  - Outputs from 01 and 02 HCAM-R codes
- *outpath* (CAM-WRAP Project Folder/Outputs)*:* CAM-WRAP Output Files
  - Outputs from CAM-WRAP code

4.2.2 Detailed Folder Structure

- *inpath_HCAM* (HCAM Project Folder)*:* HCAM Files; CAM-WRAP Input Files (Figure 14)
  - "Time Series" (Figure 15)
    - Climate time series (hydrology) input files for each climate scenario
  - "HCAM Processing" (Figure 16)
    - WMOST interim optimization and output files, specifically Wmodel.mod
    - **model_outputs** (Figure 17)
      - Wdata.dat and SpecsResults.csv files generated for each climate scenario
- *inpath_HCAMR* (HCAM-R Project Folder/Outputs): HCAM-R Output Files; CAM-WRAP Input Files (Figure 8)
  - Climate.csv, Wmodel.mod, Wdata.dat, and SpecsResults.csv files generated for each climate scenario.
- *outpath* (CAM-WRAP Project Folder/Outputs)*:* CAM-WRAP Output Files (Figure 18)
  - Wmodel.mod, Wdata.dat, and SpecsResults.csv files generated for each climate scenario. The code also outputs an outFiles.csv file for use with WMOST results processing.

Figure 14: HCAM Project Folder, which should reflect the file path specified in the *inpath_HCAM* variable

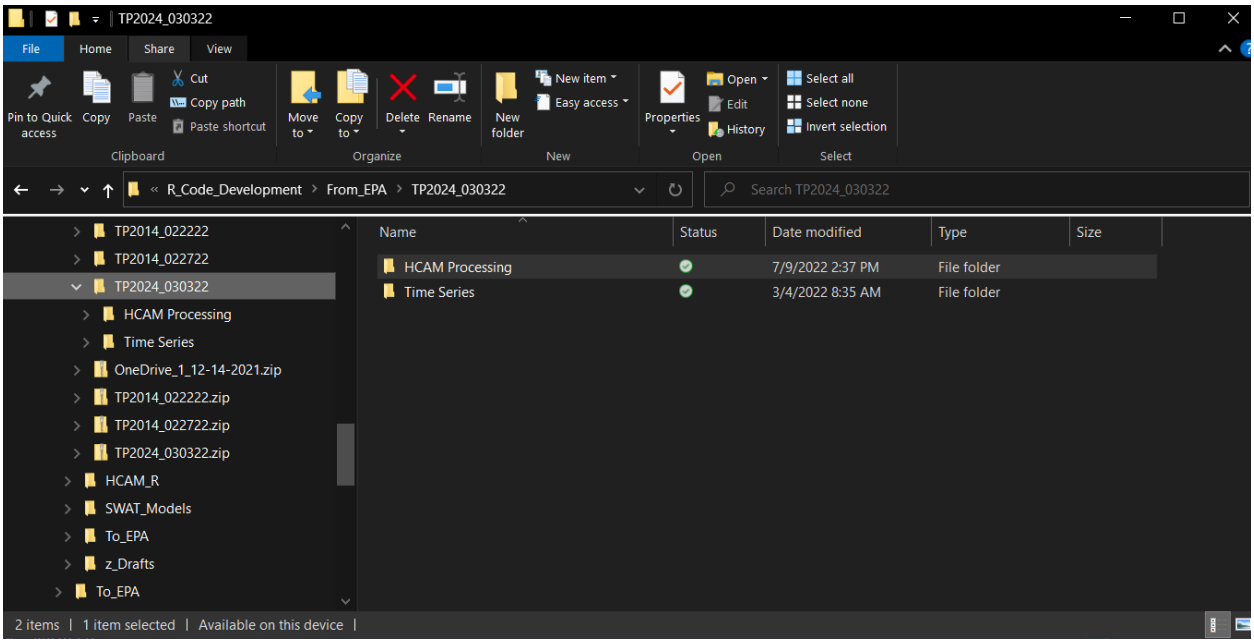


Figure 15: “Time Series” Folder

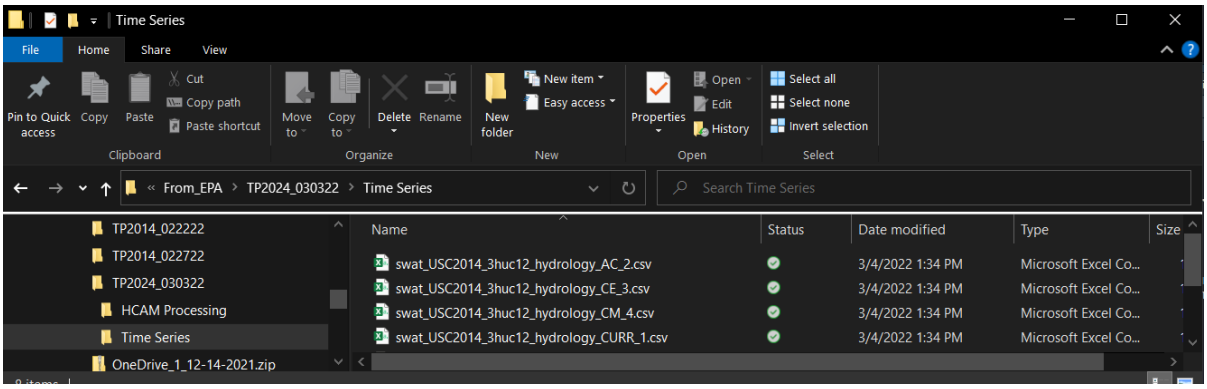


Figure 16: “HCAM Processing” Folder

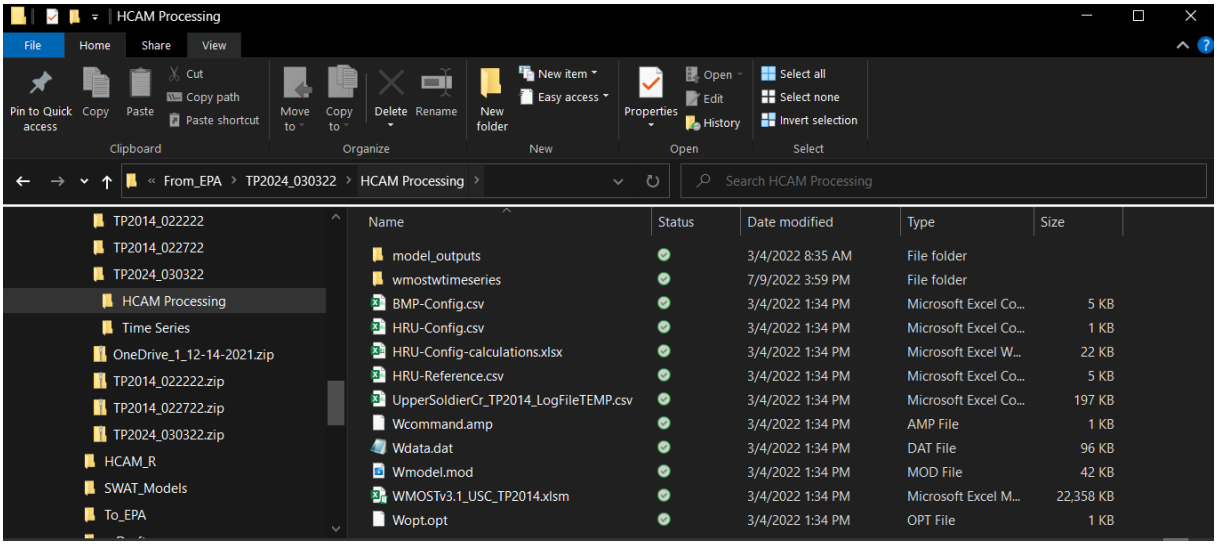


Figure 17: “model_outputs” Folder

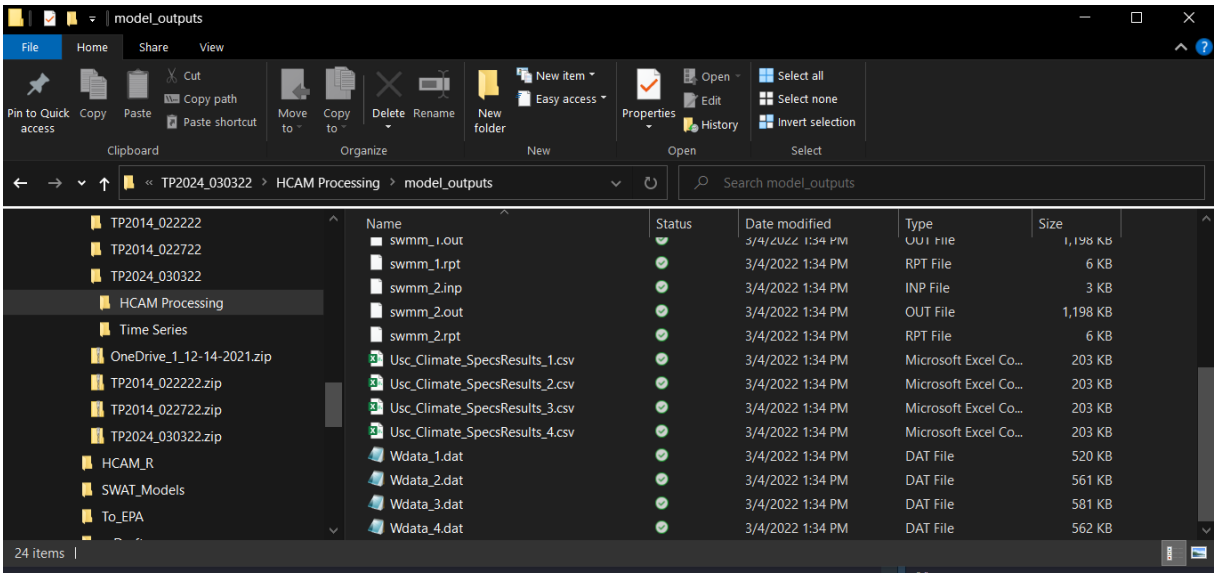
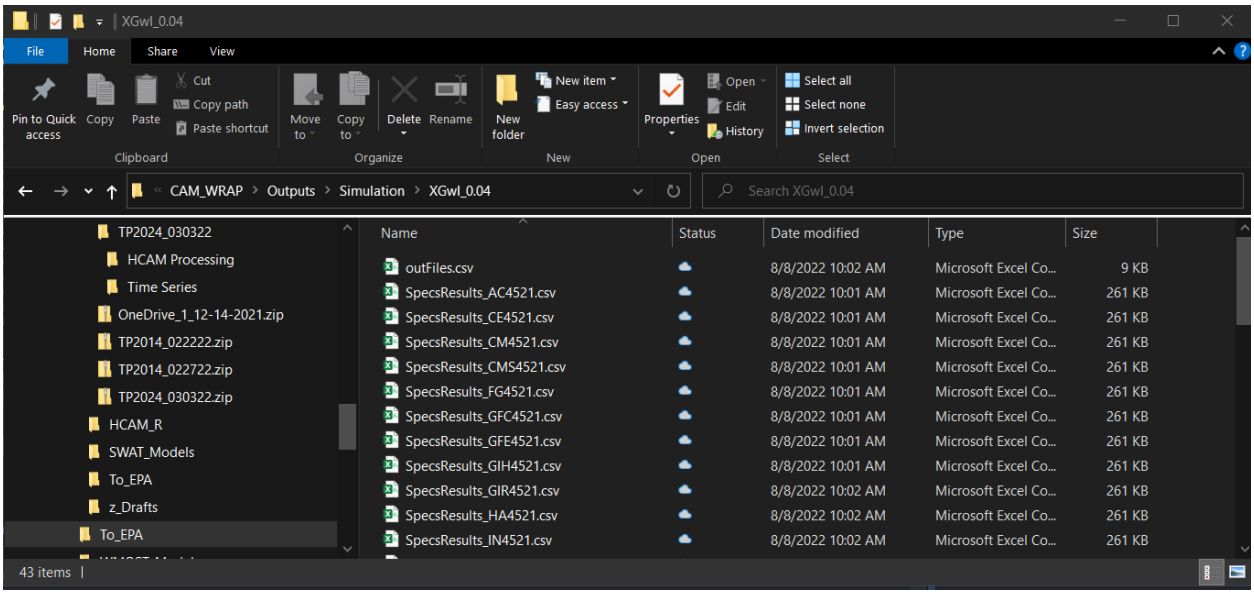


Figure 18: CAM-WRAP Outputs Folder, which should reflect the file path specified in the *outpath* variable



4.3 Inputs

The following section provides more details on the required inputs for the CAM-WRAP code, including external data files and variables specified within the code itself.

4.3.1 HCAM and HCAM-R Files

The user will need two sets of external data files to run the CAM-WRAP code: WMOST optimization files from the HCAM-R codes and WMOST optimization files and climate time series from the HCAM application.

The required HCAM files include the singular Wmodel.mod and Wdata.dat files, and SpecsResults.csv files for each climate scenario, and climate time series files (csv format) for each climate scenario. The required HCAM-R files include Wmodel.mod, Wdata.dat, SpecsResults.csv, and Climate.csv files for each climate scenario.[8]

4.3.2 Variables to be Adjusted by User in CAM-WRAP

The CAM-WRAP code includes variables that should adjust before running CAM-WRAP. Below is a list of variable names and the variable descriptions. Users should ensure that all climate-related files are input in the same order. The notes covered in this document are also available within the code itself.

There are several locations in the code marked “NOTE TO USER:”. Please read through these statements and adjust variables as needed before progressing through the code.

Table 3: CAM-WRAP Variable Descriptions

Variable Name	Variable Description
inpath_HCAM	This file path should point to the folder that includes all the CAM-WRAP input files derived from the HCAM application.
inpath_HCAMR	This file path should point to the folder that includes all the CAM-WRAP input files derived from the 02_HP_HCAM-R code.

[8] The Wdata.dat and SpecsResults.csv files output by HCAM-R can vary by climate scenario and constituent (TN, TP, and TSS). Users should only reference the files related to the constituent modeled by HCAM.

Variable Name	Variable Description
outpath	This file path should point to the folder that will be used to save the outputs of the CAM-WRAP code.
hcam_spec_filenames	This object should list the HCAM SpecsResults.csv filenames.
hcamr_spec_filenames	This object should list the HCAM-R SpecsResults.csv filenames. Users should only include SpecsResults files for one modeled constituent (TP, TN, or TSS).
hcam_wdata_filenames	This object should list the HCAM Wdata.dat filenames.
hcamr_wdata_filenames	This object should list the HCAM-R Wdata.dat filenames. Users should only include Wdata.dat files for one modeled constituent (TP, TN, or TSS).
hcam_wmodel_filenames	This object should list the HCAM Wmodel.mod filenames.
hcamr_wmodel_filenames	This object should list the HCAM-R Wmodel.mod filenames. Users should ensure that all climate-related files are input in the same order.
hcam_climate_filenames	This object should list the HCAM climate time series (.csv) filenames.
hcamr_climate_filenames	This object should list the HCAM-R climate time series (.csv) filenames.
clim_vec	This object should be defined as a list of climate scenario identifiers, listed in the same order as the climate filenames.

4.4 Outputs

The following section provides more details on outputs from the CAM-WRAP.R code, including an overall description of each output as well as its intended use.

The user should run parts 1 through 4 of the CAM-WRAP.R code to output climate scenario specific Wdata.dat, Wmodel.mod, and SpecsResults.csv files as well as an outFiles.csv file. The climate scenario specific Wdata.dat and Wmodel.mod files are ready for input into the NEOS server. Note that CAM-WRAP does not perform the model optimization. Users should refer to Appendix D for detailed instructions on how to submit model files to the NEOS server for optimization. The climate scenario specific SpecsResults.csv and singular outFiles.csv can be used to process NEOS server results for eventual use as inputs to ScenCompare. For more detailed descriptions of these files, refer to the WMOST user guide (EPA, 2018b). Following model optimization, users should use the model results and outFiles.csv files to process the results using the WMOST interface. The WMOST interface should reflect the total combined number of HRUs modeled in HCAM and HCAM-R. For example, if two urban BMPs were modeled using HCAM and one agricultural BMP was modeled using HCAM-R, the WMOST interface should reflect four HRU sets (one baseline and three managed sets).

5 References

United States Environmental Protection Agency (U.S. EPA). 2018a. “Watershed Management Optimization Support Tool (WMOST) v3: Theoretical Documentation.” Publication No. EPA/600/R-17/220).

United States Environmental Protection Agency (U.S. EPA). 2018b. “Watershed Management Optimization Support Tool (WMOST) v3: User Guide.” Publication No. EPA/600/R-17/255).

United States Environmental Protection Agency (U.S. EPA). 2018c. “ScenCompare: WMOST Climate Scenario Viewer and Comparison Post Processor. Version 1.” EPA/600/R-19/039, 2018.

United States Environmental Protection Agency (U.S. EPA). 2021. “Hydro-Climate Automation Module (HCAM) Instructions: Version 2” EPA/600/B-21/282, 2021.

6 Appendix A – SWAT Batch Climate Runs Code

Please use the following link to view the SWAT Batch Climate Runs code (HCAM-R):
https://www.epa.gov/hydrowq/wmost

7 Appendix B – HCAM Codes

Please use the following link to view the HCAM codes:
https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=353570&Lab=CEMM&simplesearch=0&showcriteria=2&sortby=pubDate&searchall=ORD-044865&timstype=&datebeginpublishedpresented=02/02/2020

8 Appendix C – CAM-WRAP Codes

Please use the following link to view the CAM-WRAP codes:

https://www.epa.gov/hydrowq/wmost

9 Appendix D – WCAP Tutorial

9.1 Background and Case Study Description

The WMOST Climate Automation Programs (WCAP) are a suite of WMOST version 3.1 add-ons that allow the user to automate the creation of runoff and recharge time series that reflect varying climate scenarios. The following sections walk users through the process of using WCAP to test the robustness of potential management practices to meet total phosphorus loading targets under varying climate scenarios for a HUC12 watershed within the Upper Soldier Creek watershed, located in northeastern Kansas. In particular, the following steps evaluate the robustness of potential management practices to meet the specified water quality target against 14 different climate scenarios under the 4.5 emission scenario for the 2021-2050 future time frame.

The data for this tutorial can be accessed… as a zip file. The user should unzip the folder before progressing through the tutorial. The "Tutorial_Data_Folder" is built with the recommended folder structure and includes the relevant datasets to run through the tutorial. The following steps will describe where the relevant files are located within the "Tutorial_Data_Folder" and the diagram linked in Appendix E provides a visual overview of the recommended folder structure for running WCAP and how the files interact with one another across the different programs. This file is provided as a separate pdf so that the user can zoom in and navigate through the diagram as needed. File folders are in boxes and files are in half-circles. In the figure and throughout this tutorial, any items (*e.g.,* folders, files, lists) that are also input variables to a downstream program are denoted in *italics*, any output folders created by WMOST-related programming (*e.g.,* WMOST or HCAM) are denoted in **bold**, and any item name (*e.g.,* folders, files, lists) in "quotes" is a name specific to this tutorial. Users are recommended to progress through this tutorial in the order that it is written, as earlier steps create inputs for later steps.

9.2 Running SWAT Batch Climate Run Codes

The SWAT Batch Climate Runs code allows users to execute a series of SWAT model runs that iterate through SWAT modeling scenarios (*i.e.,* varying agricultural BMP modeling scenarios) and future climate time series for the same baseline SWAT watershed model. Inputs and outputs from this code are necessary to run HCAM and HCAM-R.

9.2.1 Set Up Folder Structure

Within the Tutorial_Data_Folder, first, review the overall folder for running the SWAT Batch Climate Runs code ("SWAT_Batch"). Within the "SWAT_Batch" folder, there is a sub-folder named "Climate_Data_Input_Files" that holds the climate data input files. Within the "Climate_Data_Input_Files" folder, the "precipitation_1981to2015" and "temperature" folders hold the precipitation and temperature climate files respectively. The climate data input files provided for this tutorial represent 14 different climate scenarios under the 4.5 emission scenario for the 2021-2050 future time frame. Also within the "SWAT_Batch" folder, is the "SWAT_Model_Files" folder. Due to their size, the SWAT model files within the "SWAT_Model_Files" folder have been zipped. Users will need to unzip the model files before continuing with the tutorial. The SWAT model files represent two different modeling scenarios, an existing conditions scenario and a scenario where contouring practices have been applied. Lastly, within the "SWAT_Batch" folder there is an outputs folder ("SWAT_Batch_Outputs") where SWAT model results will be written. For reference, a diagram of the recommended folder structure specific to the SWAT batch climate runs code is provided in Appendix E.

9.2.2 Adjust Variables

After reviewing the folder structure on your machine, open the SWAT batch climate runs code in RStudio to adjust the necessary variables before running the code. The variables that users should adjust before running the code

are found in Section 1. Below is a list of variable names and what values the user should set the variables to. All file paths in the table below need to be revised to point to where the "Tutorial_Data_Folder" is located on the machine that will run the analysis. In the examples below, the C: drive is used as an example file location starting point. If the user does not have access to their C: drive, the Tutorial Data Folder should be saved to a folder that the user has access to. The folder locations listed after "Tutorial_Data_Folder/" do not need to be updated.

Table 4: Variable Values (Section 1 of SWAT Batch Climate Runs Code)

Variable Name	Variable Description	Variable Value
Climate_Data_path	This file path should include all 14 future climate scenario data.	*Climate_Data_path* <- "C:/…/Tutorial_Data_Folder/Climate_Data_Input_Files/"
SWAT_model_inpath	This file path should include both the SWAT model scenarios to be run (urban.dat, .gw, .sol, and .cio files).	*SWAT_model_inpath* <- "C:/…/Tutorial_Data_Folder/SWAT_Model_ Files/"
SWAT_model_outpath	This file path is where a "**Climate_Files**" folder and "**Results**" folder will be written by the code.	*SWAT_model_outpath* <- "C:/…/Tutorial_Data_Folder/SWAT_Batch_Outputs/"
Climate_Scenarios	This variable defines the abbreviations associated with the scenarios of interest.	Climate_Scenarios <- c("AC", "CE", "CM", "CMS", "FG", "GFC", "GFE", "GIH", "GIR", "HA", "IN", "MI", "MIC", "MR")
Emission_Scenario	This variable defines the label denoting the emission scenario of interest.	Emission_Scenario <- "45"
Fut_Time_Frame	This variable defines the label denoting the future time frame of interest.	Fut_Time_Frame <- "21"
Subbasins	This variable defines the subbasins to be assigned updated precipitation and temperature information.	Subbasins <- c(1, 2, 3)
Variables	This variable is used to programmatically develop the relevant columns for this analysis. In particular, the tempdegc_fut[climate].csv files have mintemp and maxtemp columns that are needed for this analysis.	Variables <- c("mintemp", "maxtemp")
Scenarios	This variable specifies which SWAT modeling scenarios will be run.	Scenarios <- c("ExistingBMPs","Contouring")
Copy_Files	This variable represents the outputs of interest that will be copied into a "**Results**" folder.	Copy_Files <- c("oput00001.hru", "oput00002.hru", "oput00003.hru")

Variable Name	Variable Description	Variable Value
SWAT executable	This variable identifies the appropriate SWAT executable for the analysis.	SWAT_executable <- "SWAT_v670_64bit_rel_WMOST_012720.exe"
WriteFiles/RunSWAT	These variables define which sections of the code are run. Users can run the section related to writing updated temperature and precipitation SWAT model input files separately from the section that iteratively runs the SWAT executable with each of the updated temperature and precipitation SWAT model input files.	WriteFiles <- TRUE RunSWAT <- TRUE

9.2.3 Run SWAT Batch Climate Runs Code

Once the variable values in Section 1 have been updated to the values in Table 4, users should select the entire code (CTRL+A) and click "Run". For each scenario, the code (as specified for this tutorial) will complete the following activities:

- Print which scenario is being processed to the console (*e.g.,* "RunScen = AC")
- Write updated temperature and precipitation files to the designated "**Climate_Files**" folder
- Run the SWAT executable for each set of temperature and precipitation files
- When the SWAT model run completes, write which scenario finished running to the "SWATLog.txt" file (*e.g.,* "Scenario completed: ExistingBMPs_AC8521_2021-06-10_09-29") and copy relevant SWAT model results to the "**Results**" folder

9.3 Running HCAM and HCAM-R

HCAM and HCAM-R automate the functionality of the Baseline Hydrology and Stormwater Hydrology Modules within WMOST v3.1. In particular, HCAM-R allows the user to process multiple Soil & Water Assessment Tool (SWAT) model runs that simulate agricultural Best Management Practices (BMP) not otherwise included within WMOST over varying climate scenarios. HCAM allows the user to batch run stormwater BMP simulations with the Storm Water Management Model (SWMM) to generate managed runoff/recharge time series over varying climate scenarios.

The following sections provide detailed instructions on running HCAM-R only. Detailed instructions on running HCAM can be found in the HCAM Technical Documentation.[9] The files of interest include the input hydrology and loadings time series (within the "HCAM_Project_Folder/Inputs/**Time_Series**" folder) and HCAM output files (Wdata.dat and SpecsResults files by climate scenario).

[9] The HCAM Technical Documentation can be found here: https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=353570&Lab=CEMM&simplesearch=0&showcriteria=2&sortby=pubDate&searchall=ORD-044865&timstype=&datebeginpublishedpresented=02/02/2020

9.3.1 Set Up Folder Structure

First, users should review the HCAM-R Project Folder within "Tutorial_Data_Folder" before running the HCAM-R code. Within this folder are two sub-folders: 1) HCAM-R inputs and 2) HCAM-R outputs. HCAM-R will also use outputs from the SWAT batch climate runs code as input. However, the associated files should not be moved from their location under the "SWAT_Batch" Folder into the HCAM-R Project Folder (see Appendix E for reference).

9.3.2 Run Preprocessing Code (01_HP_HCAM.R)

Users should first run the HCAM-R preprocessing code (01_HP_HCAM.R) to provide data on the desired modeling area that can be used to generate the required interim WMOST optimization and output files to run the HCAM-R processing code (02_HP_HCAM.R).

To do this, open the 01_HP_HCAM.R code in RStudio and adjust the necessary variables before running the code. Section 1 of the code covers variables that users should adjust before running the code. Below is a list of variable names and what values the user should set the variables to. All file paths in the table below need to be revised to point to where the "Tutorial_Data_Folder" is located on the machine that will run the analysis, but the folder locations listed after "Tutorial_Data_Folder/" do not need to be updated.

There are several locations in the codes marked "## NOTE TO USER:". Please read through these statements and adjust variables as needed before progressing through the code.

Table 5: Variable Values (Section 1 of 01_HP_HCAM.R)

Variable Name	Variable Description	Variable Value
inpath	This file path should point to the folder that includes all input files for running HCAM-R.	*inpath* <- *"*C:/…/Tutorial_Data_Folder/HCAM-R Project Folder/HCAMR_Inputs/*"*
outpath	This file path is where outputs of the 01_HP_HCAM codes will be written.	*outpath* <- "C:/…/Tutorial_Data_Folder/HCAMR_ Project_Folder/HCAMR_Outputs/"
SWAT_model_inpath	This file path should point to the folder that includes SWAT model files for each modeling scenario.	*SWAT_model_inpath* <- *"*C:/…/Tutorial_Data_Folder/SWAT_Model _Files/*"*
Scenarios	This variable defines the baseline SWAT model.	Scenarios <- c("ExistingBMPs")

Once the variable values in Section 1 have been updated, users should select the entire code (CTRL+A) and click "Run". The code can take up to an hour to run, but it will print status updates as it progresses. Once complete, the preprocessing code outputs two files: 1) temp_UserSpecs.csv and 2) climate_timeseries.csv to the outpath folder.

The climate_timeseries.csv file summarizes the precipitation and temperature time series included in the baseline SWAT model so that the user can review trends among climate variables to help decide which time period to evaluate with the WMOST model. This example focuses on the time frame from January 1, 2014 to December 31, 2014.

The temp_UserSpecs.csv file allows the user to choose HCAM-R specifications. Below is a list of HCAM-R specifications and values that should be entered into the temp_UserSpecs.csv file and resaved as "UserSpecs.csv". For reference, an associated example file in the "HCAMR_Inputs" folder (UserSpecs.csv) already includes the correct values.

Table 6: UserSpecs.csv File Details

Column Name	Description	Value
User_Choose_SUB	This column indicates which subbasins to include in the model.	Place an "X" next to subbasins 1, 2, and 3
User_Choose_HRU	This column indicates which HRUs to include in the model.	Place an "X" next to all HRUs within subbasins 1, 2, and 3
User_Agg_HRU_ID	This column allows the user to aggregate individual HRUs into aggregate groups.	Group HRUs into seven aggregate groups: crop (CRP), forest (FRS), hay (HAY), range (RNG), urban (URL), wetland (WTL), and water (WTR). See example file (UserSpecs.csv) for list of LULC codes matched to HRU aggregate groups.
User_StartDate_YYYY.MM.DD and *User_EndDate_YYYY.MM.DD*	These columns indicate the model start and end date.	Start: 1/1/2014 End: 12/31/2014
Scenario_Name	These user-specified file paths should point to the folders that include outputs from the SWAT model climate scenario runs. Each run needs a file path.	*SWAT_model_*outpath/**Results**/BMP Scenario x/Climate Scenario y folder file path. "x" denotes the BMP scenarios "Existing BMPs" or "Contouring" and y designates the climate scenario (i.e., AC4521, etc.) See Appendix E for a diagram.
Managed_Sets	This column indicates the managed set number that corresponds to the user-specified file path in the *Scenario_Name* column. This column must have a numeric value.	ExistingBMPs = 1; Contouring = 2
Climate_Scenario	This column indicates the climate scenario identifier or abbreviation that corresponds to the user-specified file path in the *Scenario_Name* column.	Climate scenario abbreviations should match the subfolder listed in the *Scenario_Name* column.

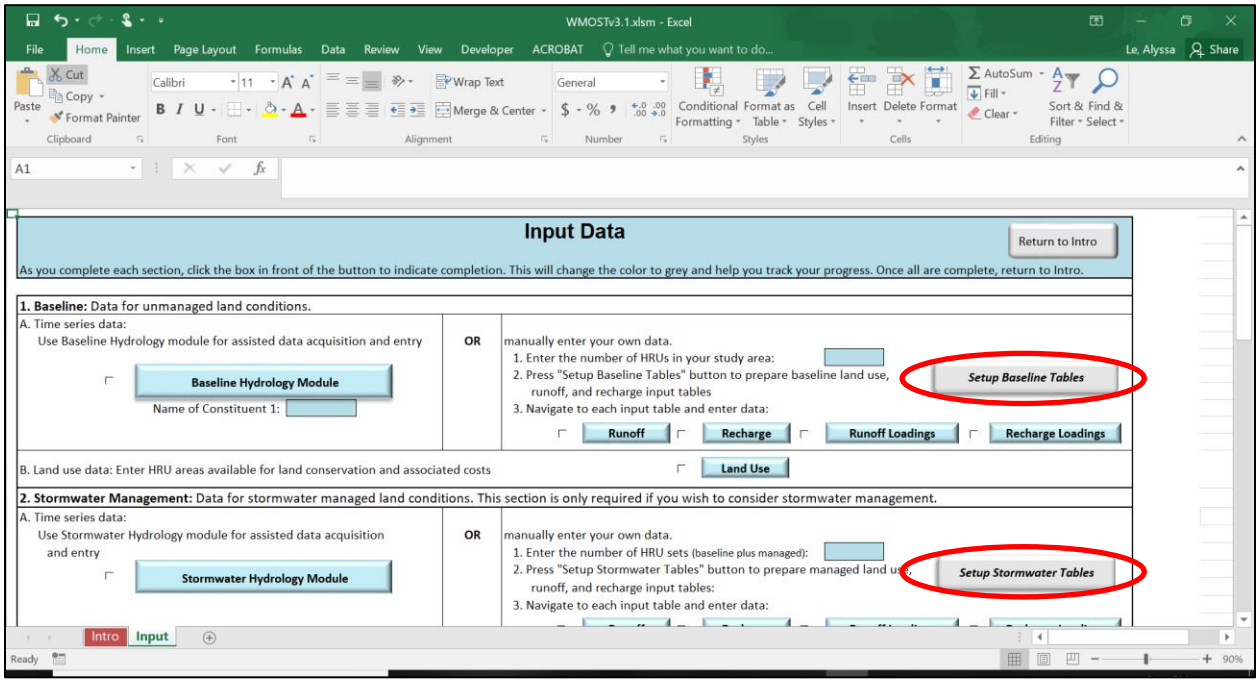
9.3.3 Set Up and Create Interim WMOST Files

It is recommended that users who are unfamiliar with WMOST model inputs and outputs refer to the WMOST documentation (EPA, 2018a; EPA, 2018b) for any additional clarification on the following steps to fill out the WMOST interface and generate the necessary interim files, including Wdata.dat, Wmodel.mod, and SpecsResults.csv.

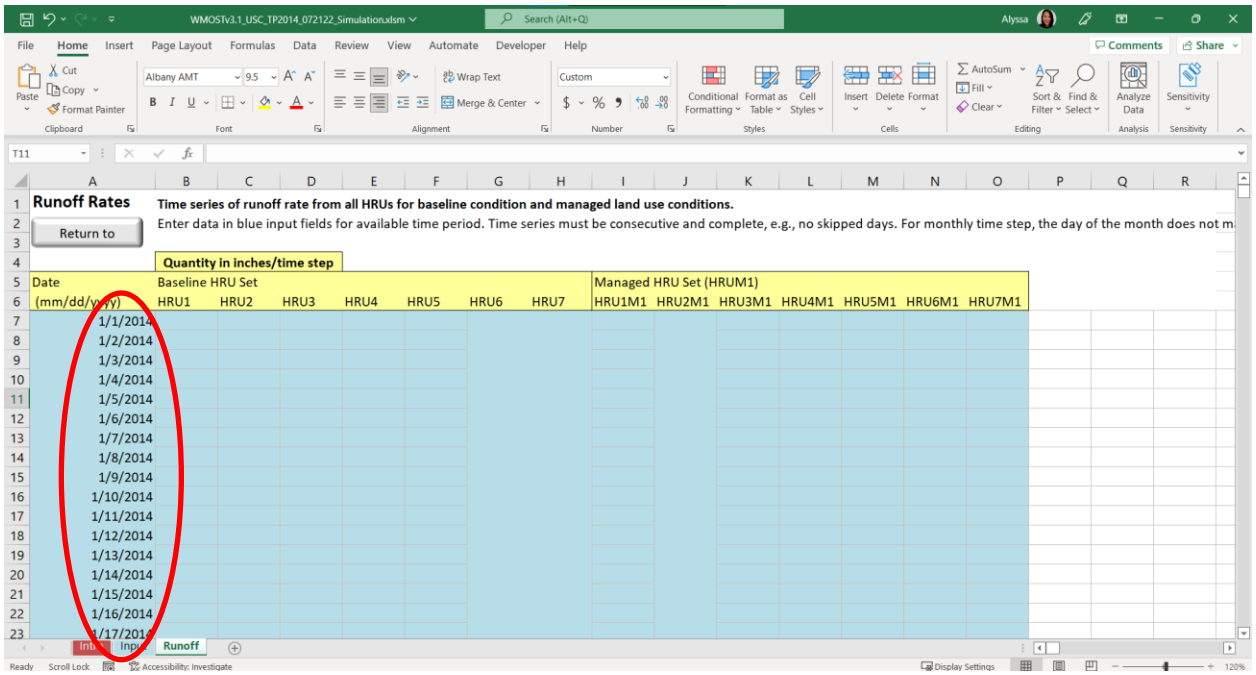
Users should first open WMOST v3.1 in Excel. The .xlsm file will open to one active worksheet entitled "Intro". Overall, interaction with the WMOST 3.1 interface will largely be the same as for earlier versions except for the entry of runoff and recharge hydrology and loadings time series, including the Baseline Hydrology and Stormwater Hydrology Modules.[10]

[10] For detailed information on how to fill out the rest of the WMOST input pages, please refer to the WMOST User Guide (Sections 3.4 through 3.8).

1) Set up the baseline and stormwater managed runoff and recharge tables based on the number of HRUs and managed sets chosen in the UserSpecs.csv file using the "Setup Baseline Tables" and "Setup Stormwater Tables" buttons on the "Input" sheet. For this example, setup the runoff and recharge tables for seven HRUs and two managed sets. The fields in the baseline and stormwater managed runoff and recharge tables will be left blank.

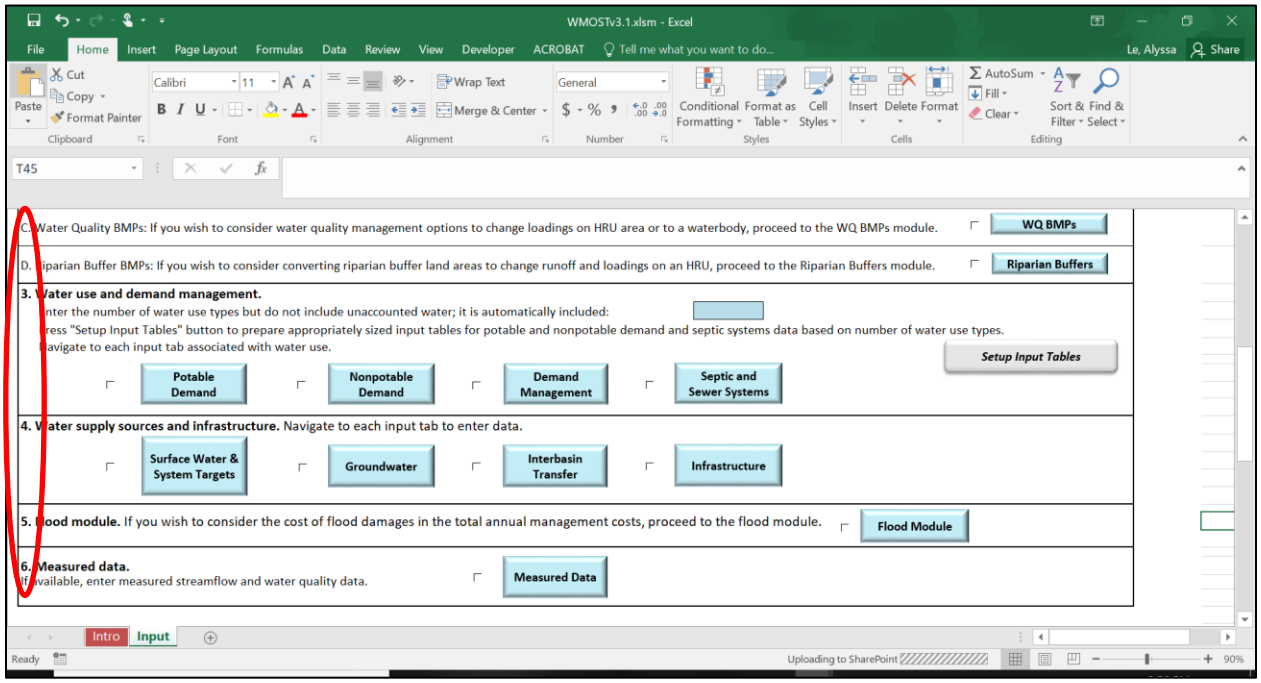


2) Enter the model dates manually on the "Runoff" sheet (Baseline Hydrology Module). For this example, start at 1/1/2014 and end at 12/31/2014, progressing in daily increments.

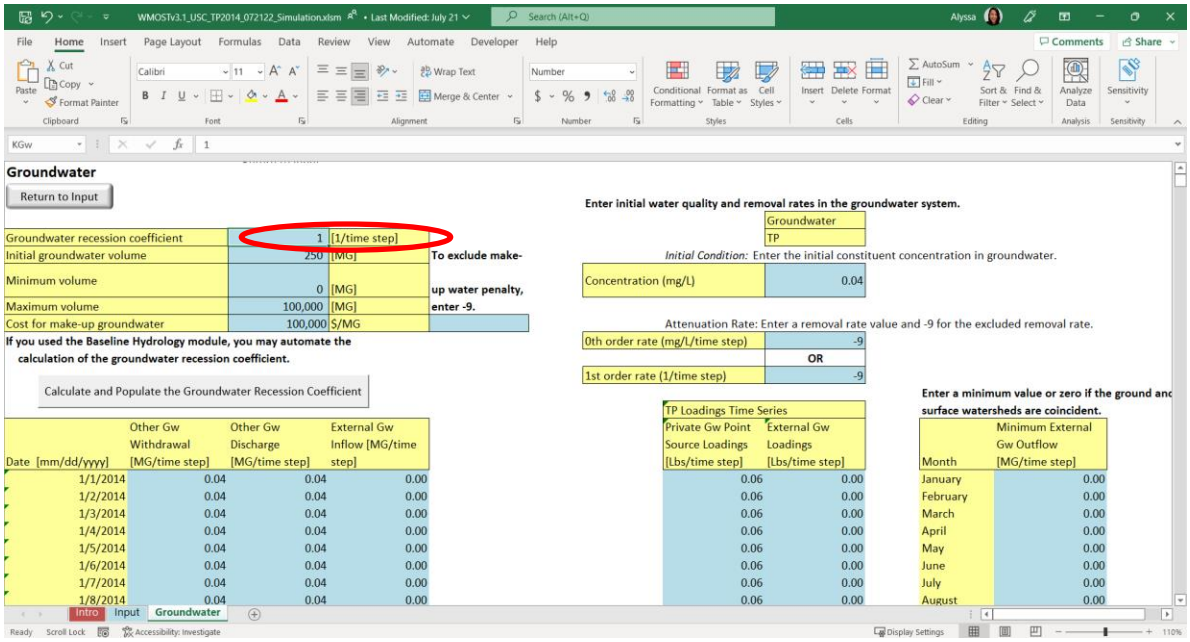


As a reminder, you do *not* need to process or enter any runoff/recharge time series data or create any managed sets. However, you should fill in the other relevant WMOST input pages, such as the Potable and

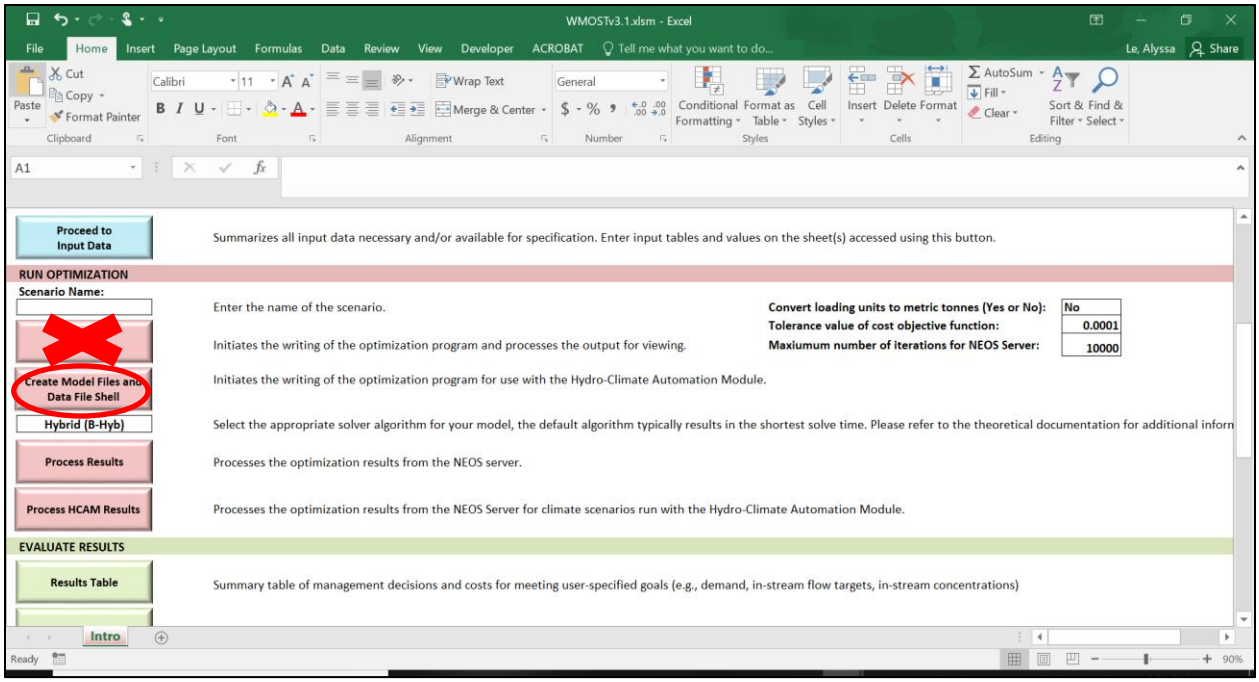
Nonpotable Demand pages and Infrastructure page (WMOST User Guide Sections 3.3 through 3.8, Sections 2c through 6 on the **Input** sheet).



3) In particular, HCAM-R calculates scenario-specific KGw values from SWAT output files (near the end of Part 2 in 02_HP_HCAM.R). In order to accurately include the updated KGw value in the Wmodel.mod (beginning of Part 4 in 02_HP_HCAM.R) and SpecsResults.csv files (Part 5 in 02_HP_HCAM.R) for each climate scenario, the user must set the KGw value in the WMOST model (Groundwater tab) to one. Setting the initial KGw value to one ensures that an accurate initial groundwater volume is included in the interim Wmodel.mod file.



After inputting the necessary data, press the "Create Model Files and Data File Shell" button on the "Intro" sheet. Do not press the "Optimize" button.



Pressing the button will create five files: 1) a model file (Wmodel.mod), 2) a command file (Wcommand.amp), 3) a data file (Wdata.dat), 4) an options file (Wopt.opt), and 5) an input data log file (a csv file ending in "LogFileTEMP"). The model file (Wmodel.mod), data file (Wdata.dat) and log file will all be updated by WCAP in later steps. For reference, a completed WMOST file and associated WMOST model files can be found in the "Tutorial_Data_Files/HCAMR_Project_Folder/HCAMR_Inputs" folder.

9.3.4 Run HCAM-R Code (02_HP_HCAM.R)

The 02_HP_HCAM.R code should be run in three steps: 1) the top of the code to establish model specifications, 2) Parts 2 through Part 4A, and then 3) Part 4B to Part 6 after filling out the HRUSpecs.csv file.

Users should open the 02_HP_HCAM.R code in RStudio to adjust the necessary variables before running through Part 4A of the code. The section titled "Variables to Adjust" contains variables that users should adjust before running the code. Below is a list of variable names and what values the user should set the variables to. All file paths in the table below need to be revised to point to where the "Tutorial_Data_Folder" is located on the machine that will run the analysis, but the folder locations listed after "Tutorial_Data_Folder/" do not need to be updated.

There are several locations in the codes marked "## NOTE TO USER:". Please read through these statements and adjust variables as needed before progressing through the code.

Table 7: Variable Values (Beginning of 02_HP_HCAM.R)

Variable Name	Variable Description	Variable Value
inpath	This file path should point to the folder that includes all input files for running HCAM-R (i.e., Wmodel.mod, Wdata.dat, UserSpecs.csv, etc.).	*inpath* <- *"*C:/…/Tutorial_Data_Folder/HCAMR_Project_Folder/HCAMR_Inputs/*"*
outpath	This file path is where outputs of the 02_HP_HCAM codes will be written.	*outpath* <- "C:/…/Tutorial_Data_Folder/HCAMR_Project_Folder/HCAMR_Outputs/"
SWAT_model_inpath	This file path should point to the folder that includes SWAT model files for each modeling scenario.	*SWAT_model_inpath* <- *"*C:/…/Tutorial_Data_Folder/SWAT_Batch/SWAT_Model_Files/*"*
const, ru_const, re_const, ru_sum_const, and re_sum_const	These variables define constituents processed in the WMOST files. The current 02_HP_HCAM code includes nitrogen, phosphorus, and sediment, but the user can opt to include fewer constituents.	const <- c("TN","TP","TSS") ru_const_lbs <- c("Ru_N_lbs_wmean","Ru_P_lbs_wmean","SYLD_lbs_wmean") ru_const_kg <- c("Ru_N_kg_wmean","Ru_P_kg_wmean","SYLD_kg_wmean") re_const_lbs <- c("RCHG_N_lbs_wmean","Re_P_lbs_wmean","Re_SYLD_wmean") re_const_kg <- c("RCHG_N_wmean","Re_P_kg_wmean","Re_SYLD_wmean") ru_sum_const <- c("Ru_N_lbs_wmean_sum","Ru_P_lbs_wmean_sum","SYLD_lbs_wmean_sum") re_sum_const <- c("RCHG_N_lbs_wmean_sum","Re_P_lbs_wmean_sum","Re_SYLD_wmean_sum")
dir_dep	This selection allows the user to consider direct deposition to streams from cattle grazers in RNGE HRU runoff loadings if "YES" is specified.	dir_dep <- "YES"
ManagedSets	This variable defines the managed sets considered in the 02_HP_HCAM code.[11]	ManagedSets <- c("ExistingBMPs","Contouring")

Once the variable values at the top of the code have been updated, users should select through Part 2 of the code and click "Run". At this point, the order of aggregate HRUs in the HRUSpecs.csv file will match the order of

[11] The order in which the user defines *Managed_Sets* in the UserSpecs.csv file must match the order in which the user defines managed sets in the *ManagedSets* character vector of the 02_HP_HCAM script. For example, within the example file, Managed_Set 1 refers to the ExistingBMPs managed set, while Managed_Set 2 refers to the Contouring managed set. In the 02_HP_HCAM.R script, the *ManagedSets* character vector is defined as ManagedSets <- c(ExistingBMPs, Contouring), where element 1 of the vector is ExistingBMPs and element 2 is Contouring.

aggregate HRUs defined in the UserSpecs.csv file. In order to match the files included for the case study, users should adjust the agg_HRU_vec variable (see example below).

Table 8: Variable Values (Part 1 of 02_HP_HCAM.R)

Variable Name	Variable Description	Variable Value
agg_HRU_vec	This specification allows the user to shift the order of aggregate HRU identifiers from the HRUSpecs.csv file to match those listed in the UserSpecs.csv file.	agg_HRU_vec <- c(agg_HRU_vec[2],agg_HRU_vec[4],agg_HRU_vec[1],agg_HRU_vec[3],agg_HRU_vec[5],agg_HRU_vec[6],agg_HRU_vec[7])

Once the agg_HRU_vec variable has been set users should select from the end of Part 2 through Part 4A of the code and click "Run". This portion of the code will output a template HRU_Specs.csv file (temp_HRUSpecs.csv) that the user should use to choose WMOST model specifications, including HRU minimum and maximum area and capital and O&M costs for BMP application to the various HRUs, mimicking selections on the Land_Use tab in the included WMOST file. For reference, an associated example file ("HCAMR_ProjectFolder/HCAMR_Inputs/HRUSpecs.csv) already includes the correct values. In particular, the file sets up a WMOST model that allows for contouring to be applied to all crop (CRP) HRUs within the model.

Once the HRUSpecs.csv file has been filled out, users should select Part 4B through Part 6 of the code and click "Run". This portion of the code outputs Wmodel.mod, Wdata.dat, SpecsResults.csv, Climate.csv, and outFiles.csv files. The Wdata.dat and SpecsResults.csv files are generated for each climate scenario and constituent (TN, TP, and TSS). The Wmodel.mod and Climate.csv files are generated for each climate scenario. The outFiles.csv files are generated for each constituent. For a more detailed description of these files, refer to the WMOST user guide (EPA, 2018b) and HCAM user instructions (EPA, 2021). These files can be used as input to CAM-WRAP.

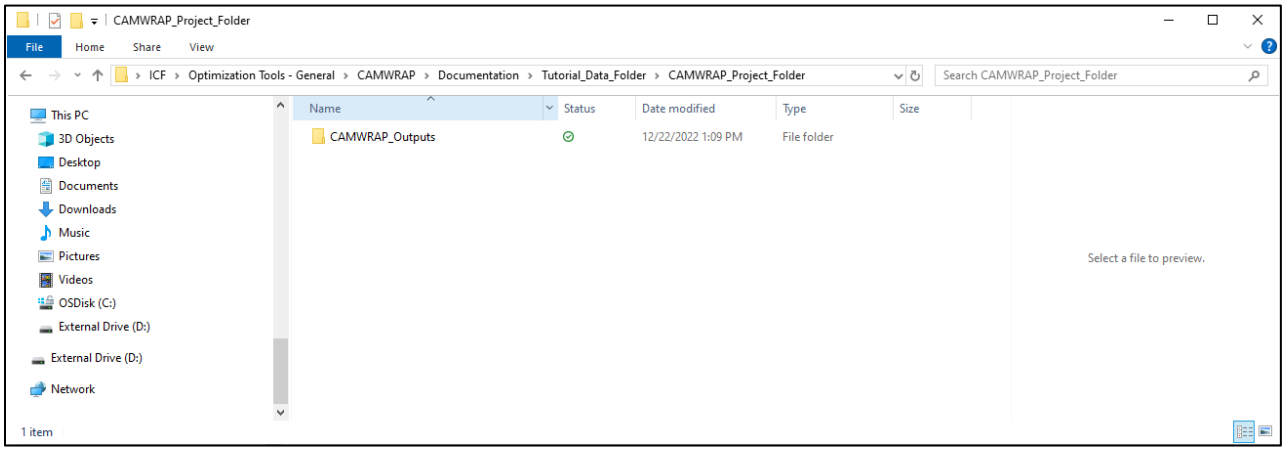
9.4 Running CAM-WRAP

CAM-WRAP is a wrapper code that combines the output files from HCAM-R and HCAM to develop the set of WMOST files that are ready for optimization. The WMOST files can then be uploaded to the NEOS server for optimization and the optimized results can be downloaded to be processed in the WMOST macro-enabled Excel file.

9.4.1 Set Up Folder Structure

First, users should review the CAM-WRAP Project folder before running the CAM-WRAP code. Within the CAM-WRAP Project Folder is one sub-folder for CAM-WRAP outputs: "CAMWRAP_Outputs". CAM-WRAP will use outputs from the HCAM and HCAM-R codes as input. However, the associated files should not be moved from their locations under the HCAM and HCAM-R Project Folders (see Appendix E for reference). The inputs for CAM-WRAP include the WMOST optimization files (.mod, .dat, etc.) and Specs Results files (.csv) output from HCAM-R and HCAM.

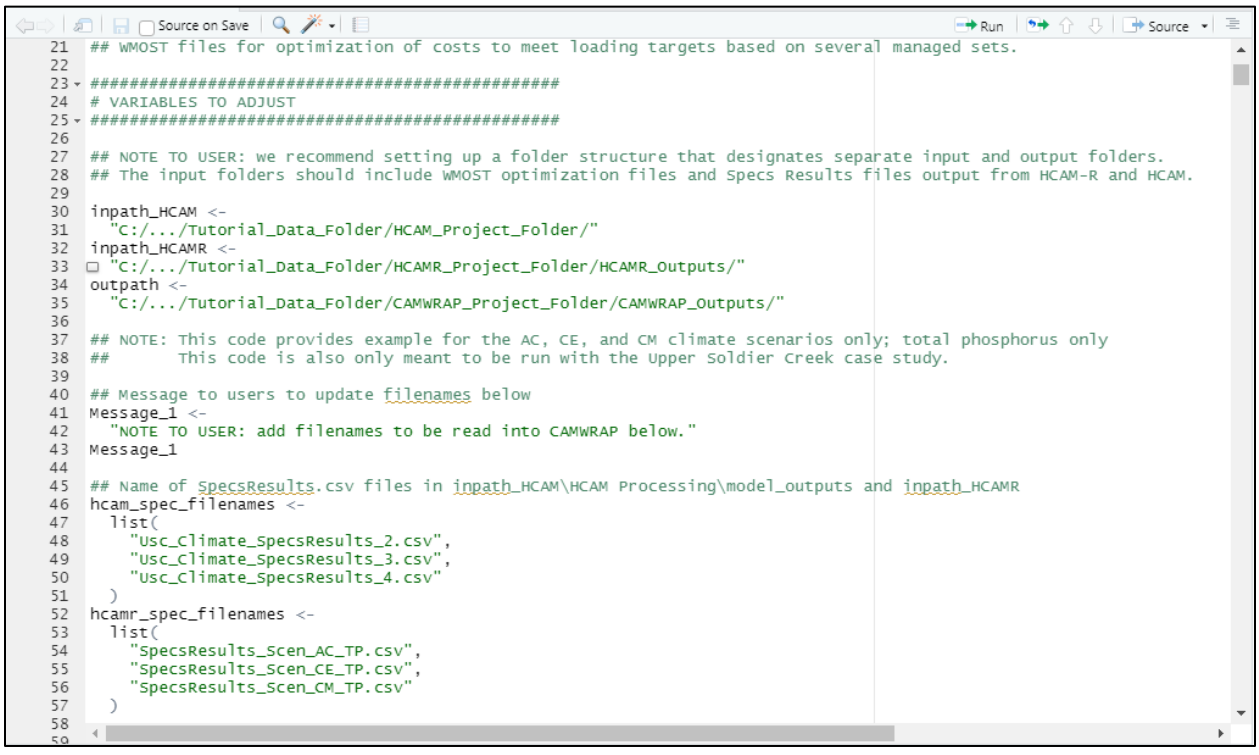
FIGURE 19: SCREENSHOT OF THE CAMWRAP PROJECT FOLDER



9.4.2 Run CAM-WRAP

Users should open the CAMWRAP.R code in RStudio to install the necessary packages and adjust the necessary variables before running the code. Users will only need to run the code to install the pacman package once. The section titled "Variables to Adjust" contains variables that users should adjust before running the code.

FIGURE 20: SCREENSHOT OF THE VARIABLES TO ADJUST SECTION IN CAMWRAP



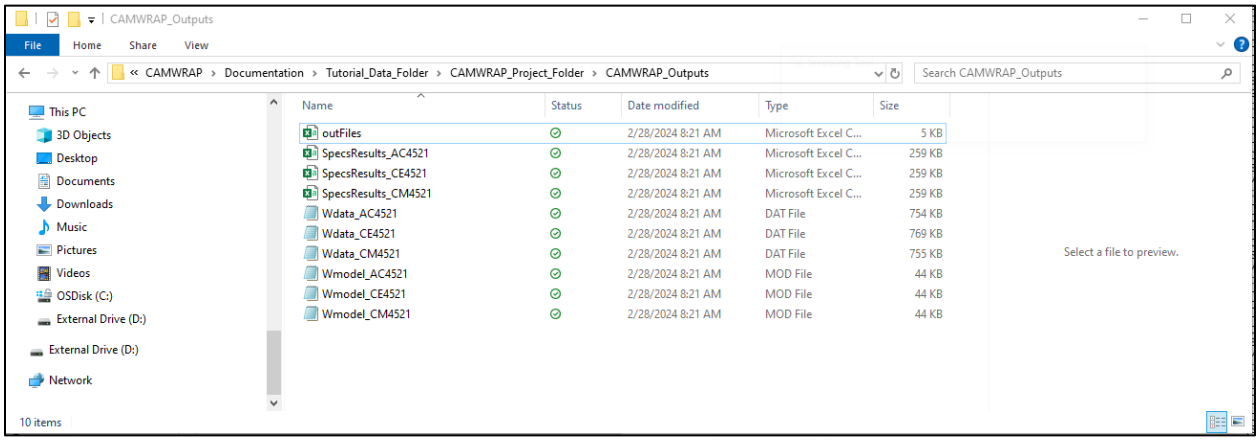
Below is a list of variable names and what values the user should set the variables to. All file paths in the table below need to be revised to point to where the "Tutorial_Data_Folder" is located on the machine that will run the analysis, but the folder locations listed after "Tutorial_Data_Folder/" do not need to be updated. Users need to define lists of filenames for specific types of files from both HCAM and HCAM-R as well as the climate scenario identifiers. The climate identifiers are a list of scenario identifiers as strings. The climate scenario identifiers must be in the same order as the climate filenames from *hcam_climate_filenames* and *hcamr_climate_filenames*.

Table 9: Variable Values (Beginning of CAMWRAP.R)

Variable Name	Variable Description	Variable Value
Inpath_HCAM	This file path should point to the folder that includes all output files from running HCAM (i.e., Wmodel.mod, Wdata.dat, UserSpecs.csv, etc.).	*inpath_HCAM <-* *"*C:/…/Tutorial_Data_Folder/HCAM_Project_Folder/*"*
Inpath_HCAMR	This file path should point to the folder that includes all output files from running HCAM-R (i.e., Wmodel.mod, Wdata.dat, UserSpecs.csv, etc.).	*inpath_HCAMR <-* "C:/…/Tutorial_Data_Folder/HCAMR_Project_Folder/HCAMR_Outputs/"
Outpath	This file path should point to the folder created in Section 1.1 where the CAM-WRAP outputs will be saved.	*outpath <-* "C:/…/Tutorial_Data_Folder/CAMWRAP_Project_Folder/CAMWRAP_Outputs/"
hcam_spec_filenames	Name of SpecsResults.csv files in inpath_HCAM	*hcam_spec_filenames <- list("Usc_Climate_SpecsResults_1.csv", "Usc_Climate_SpecsResults_2.csv", …)*
hcamr_spec_filenames	Name of SpecsResults.csv files in inpath_HCAMR	*hcamr_spec_filenames <- list("SpecsResults_Scen_AC4521_TP.csv", "SpecsResults_Scen_CE4521_TP.csv", …)*
hcam_wdata_filenames	Name of Wdata.dat files in inpath_HCAM	*hcam_wdata_filenames <- list("Wdata_1.dat", "Wdata_2.dat", …)*
hcamr_wdata_filenames	Name of Wdata.dat files in inpath_HCAMR	*hcamr_wdata_filenames <- list("Wdata_Scen_AC4521_TN.dat", "Wdata_Scen_AC4521_TP.dat", …)*
hcam_wmodel_filenames	Name of Wmodel.mod file in inpath_HCAM	*hcam_wmodel_filenames <- list("Wmodel.mod")*
hcamr_wmodel_filenames	Name of Wmodel.mod files in inpath_HCAMR	*hcamr_wmodel_filenames <- list("Wmodel_Scen_AC4521.mod", "Wmodel_Scen_CE4521.mod", …)*
hcam_climate_filenames	Name of climate.csv files in inpath_HCAM	*hcam_climate_filenames <- list("swat_USC2014_3huc12_hydrology_AC4521_1.csv", "swat_USC2014_3huc12_hydrology_CE4521_2.csv" …)*
hcamr_climate_filenames	Name of Wmodel.mod files in inpath_HCAMR	*hcamr_climate_filenames <- list("Climate_AC4521.csv", "Climate_CE4521.csv", …)*
Clim_vec	Name of climate identifiers for each of the 14 climate scenarios	*clim_vec <- c("AC4521", "CE4521", "CM4521", …)*

After the input and output paths and files are defined, users should select the entire code (CTRL+A) and click "Run". Output files (climate scenario specific Wdata.dat, Wmodel.mod, and SpecsResults.csv files as well as an outFiles.csv file) will be written automatically to the designated folder by *outpath*. After a successful run, several QA dataframes will be displayed to allow the user to confirm the consistency of climate time series files from HCAM and HCAM-R. If the magnitude of the fields PREC_DIFF (difference in precipitation) and TEMP_DIFF (difference in temperature) in the QA dataframes are substantial, users may have set up the climate time series in different orders across HCAM and HCAM-R. With the CAM-WRAP code successfully run, the user can upload the CAM-WRAP results to the NEOS server for optimization. For detailed instruction on how to upload files to the NEOS server and process optimization results in WMOST, refer to the WMOST user guide (EPA, 2018b) and HCAM user instructions (EPA, 2021).

FIGURE 21: SCREENSHOT OF THE CAMWRAP OUTPUT FOLDER AFTER SUCCESSFUL CODE RUN



10 Appendix E – WCAP Folder Structure

Please use the following link to view the high-resolution WCAP folder structure PDF: